Marine Fisheries REVIEW

May-June 1979

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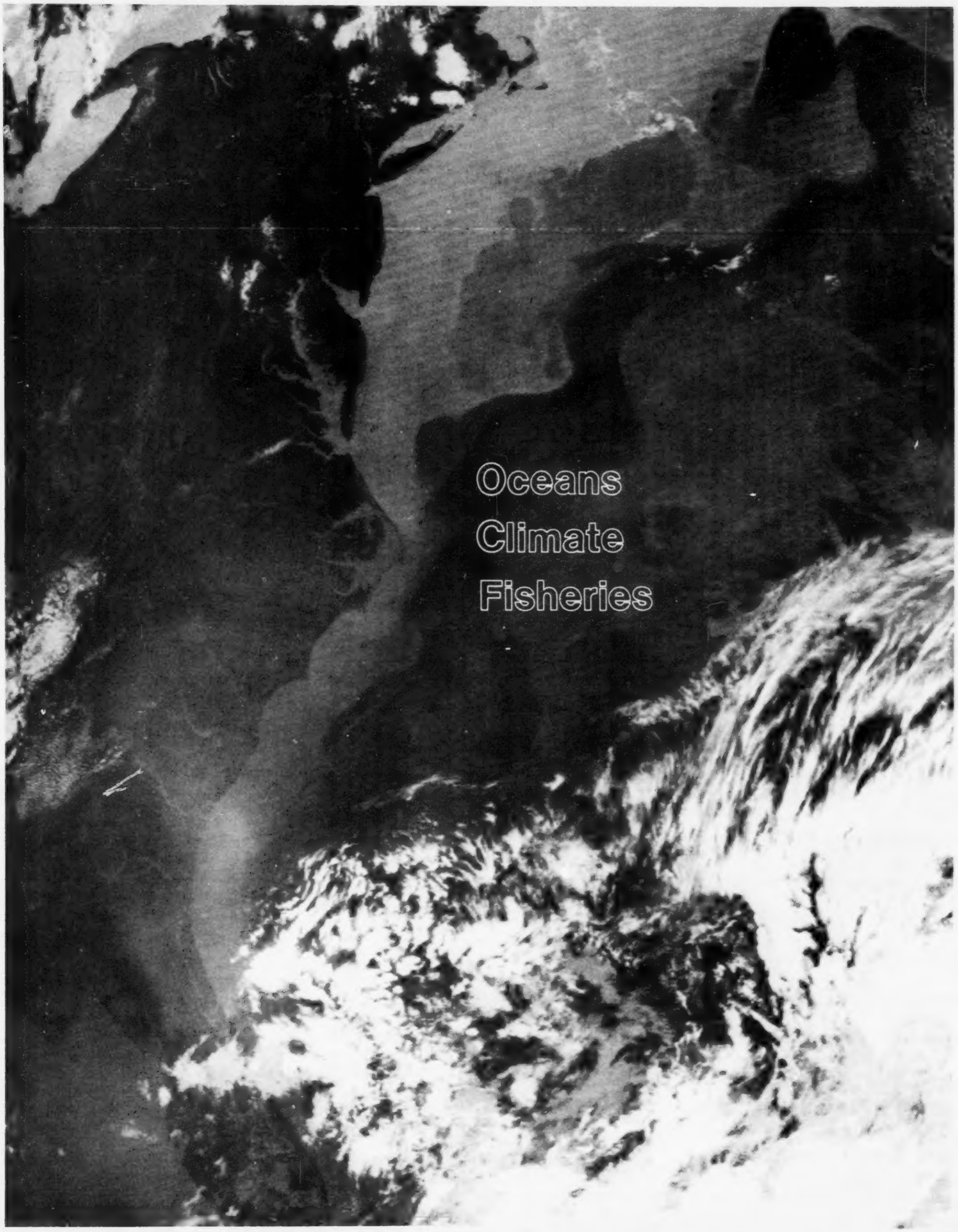

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On the cover: This infrared image, taken 13 April 1977, shows the Gulf Stream as it meanders from Florida to Cape Hatteras and northeastward into the Atlantic Ocean. Warm areas appear dark; cold areas appear white.

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Relationship Between Marketing Category (Count) Composition and Ex-Vessel Value of Reported Annual Catches of Shrimp in the Eastern Gulf of Mexico

CHARLES W. CAILLOUET, FRANK J. PATELLA, and WILLIAM B. JACKSON

ABSTRACT—The effect on ex-vessel value of marketing category (count= number of shrimp per pound, heads-off) composition of reported annual catches of brown shrimp, Penaeus aztecus, *white shrimp,* P. setiferus, *and pink shrimp,* P. duorarum, *in the eastern Gulf of Mexico. Shrimp management implications are discussed.*

Introduction

Caillouet and Patella (1978) showed how marketing category (count=number of shrimp per pound, heads-off) composition of the reported annual catches of brown shrimp, *Penaeus aztecus*, and white shrimp, *P. setiferus*, influenced the value of these catches from two Gulf states, Texas and Louisiana, which have different shrimp laws (Christmas and Etzold, 1977) and shrimp harvesting strategies. In Texas, the catch of small shrimp is greatly restricted, but in Louisiana there are large catches of small shrimp. Consequently, for a given weight of catch, the ex-vessel value of white and brown shrimp harvested at larger sizes in Texas was 1.2 and 1.6 times higher, respectively, than that of white and brown shrimp harvested at smaller sizes in Louisiana. This paper extends the analysis to the shrimp fisheries of the eastern Gulf of Mexico, namely those of Mississippi, Alabama, and west coast of Florida, and includes pink shrimp, *P. duorarum,* as well as brown and white shrimp. In this paper, harvesting strategy refers to the sizes of shrimp harvested, retained, and landed.

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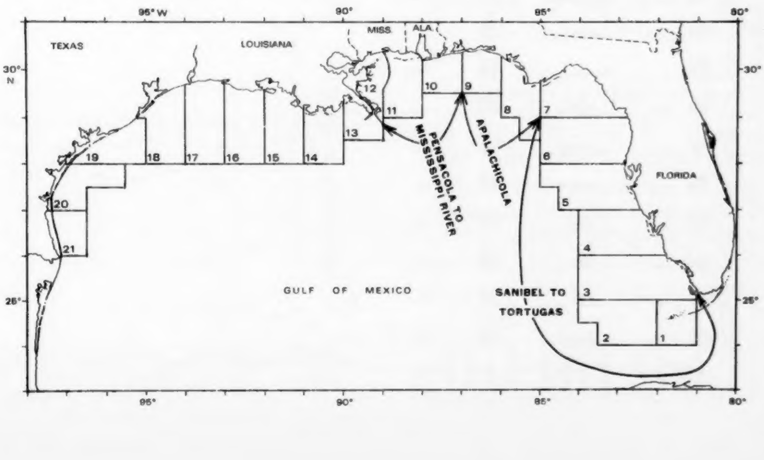
Brief Description of Fisheries and Data

Shrimp fisheries of the eastern Gulf of Mexico are divided into three major statistical regions (Fig. 1): Pensacola to Mississippi River (statistical areas 10-12), Apalachicola (statistical areas 7-9), and Sanibel to Tortugas (statistical areas. 1-6). These regions encompass that part of the Louisiana coast east of the Mississippi River, the coasts of Mississippi and Alabama, and the west coast of Florida. Only the dominant species in each of these three regions are considered herein. Pink

Figure 1.—Statistical areas used in reporting Gulf Coast shrimp data.



shrimp is the dominant species in reported catches from the Apalachicola and Sanibel to Tortugas regions, and brown and white shrimp dominate the reported catches in the Pensacola to Mississippi River region (Fig. 2). The Apalachicola region appears to be a zone of transition from brown and white to pink shrimp.

Brown, white, and pink shrimp spend the juvenile and subadult phases of their life cycles in inshore waters and the adult and larval phases in offshore waters (Fig. 3). They are first exploited by the inshore fisheries, then those that survive emigrate from the estuaries and become vulnerable to the offshore fisheries.

Numbers of shrimp vessels (5 net registry tons and larger, Fig. 4) and their average size (net registry tons, Fig. 5) have increased gradually in Mississippi, Alabama, and Florida. Numbers of shrimp boats (less than 5 net registry tons, Fig. 6) have remained relatively constant in Alabama and Florida but have increased in Mississippi. The number of vessels is higher in Florida than in Alabama and Mississippi (Fig. 4), and Alabama and Florida vessels average larger than those of

Figure 3.—Relationship among inshore and offshore shrimp fisheries and estuarine and oceanic phases of brown, white, and pink shrimp life cycles.

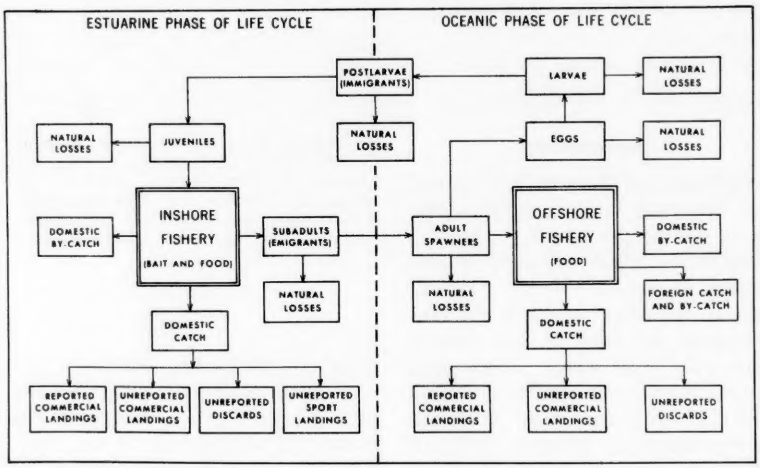


Figure 2.—Species composition (percent by weight, heads-off) of reported annual catches of shrimp from Pensacola to Mississippi River (statistical areas 10-12), Apalachicola (statistical areas 7-9), and Sanibel to Tortugas (statistical areas 1-6) regions, 1959-75.

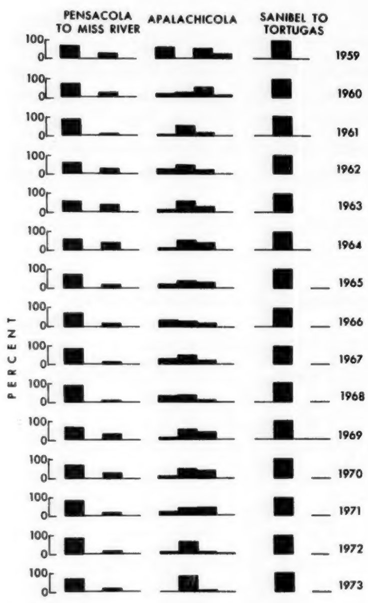
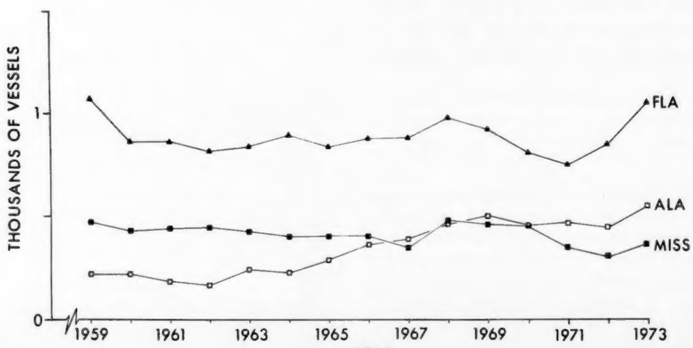


Figure 4.—Reported annual number (thousands) of shrimp vessels (5 net registry tons or larger) in Mississippi, Alabama, and Florida west coast, 1959-73.



Mississippi (Fig. 5). Numbers of fishermen operating from vessels have increased in Florida and Alabama but have declined somewhat in Mississippi (Fig. 7), whereas Mississippi has larger numbers of fishermen operating from boats than either Alabama or Florida. The results of these differences and trends in characteristics of the fisheries, as well as differences in state laws and harvesting strategies, also are reflected in the count composition of the reported annual catches in the Pensacola to Mississippi River, Apalachicola, and Sanibel to Tortugas regions (Fig. 8-11).

Data and Methods

This paper deals with reported annual catches of shrimp during 1959-75, the years for which annual summaries of the Gulf Coast shrimp data (National Marine Fisheries Service, 1960-76) were available. Combined inshore and offshore catches were used. They represent catches landed by U.S. craft at U.S. ports along the coast of the Gulf of Mexico. The reported catches represent only a portion of the total annual catches, since some of the commercial landings (including those of foreign craft), discarded undersized shrimp, and landings by sport fishermen are not adequately sampled and therefore are not reported (Fig. 3). The proportion of the total annual catch that is not reported is unknown, but we believe that the count composition of the reported catch is a reasonably good reflection of shrimp population characteristics and harvesting strategy combined. We used annual summaries of reported catch in pounds (heads-off) within eight marketing or count categories (number of shrimp per pound, heads-off: $\geq$68, 51-67, 41-50, 31-40, 26-30, 21-25, 15-20, and $<$15) from the Gulf Coast shrimp data.

To illustrate the effect of count composition on ex-vessel value of reported catches of brown, white, and pink shrimp, average value per pound (heads-off) was calculated for each species from annual total dollars and pounds by size category (for the entire U.S. Gulf Coast) as reported in National Marine Fisheries Service (1976). These averages were multiplied by reported annual catches in each count category, species, and region to estimate annual value (in 1975 units) of the catches by count category, species, and region. Summation over count categories estimated total annual ex-vessel value (in 1975 units) of the catches by species and region. Though 1975 units were used because data were available, similar methods could be applied as more recent statistics become available. Linear regression lines were fitted to the data points and through the origin for each species and region to estimate average ex-vessel value per pound (the slope of the line).

Figure 5.—Annual average reported registry tons per shrimp vessel (5 net registry tons or larger) in Mississippi, Alabama, and Florida west coast, 1960-73.

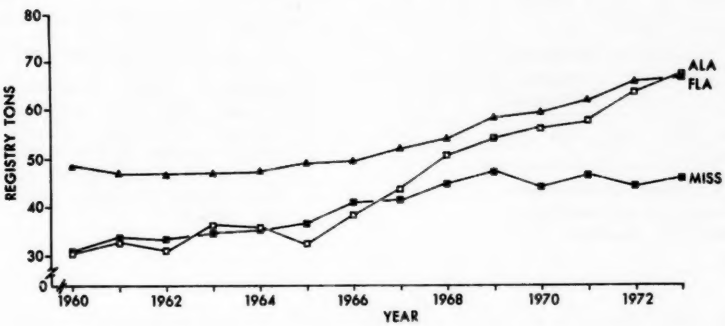
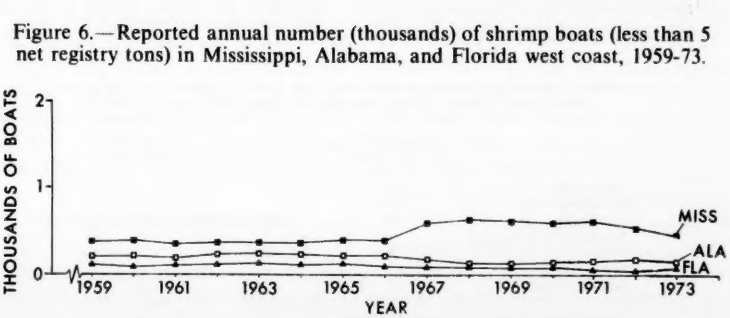


Figure 6.—Reported annual number (thousands) of shrimp boats (less than 5 net registry tons) in Mississippi, Alabama, and Florida west coast, 1959-73.



Results and Discussion

In the Pensacola to Mississippi River region (Fig. 8), count composition of reported catches of brown shrimp has remained relatively stable, but that of white shrimp has fluctuated somewhat (Fig. 9). Count composition of reported catches of pink shrimp has remained relatively stable in the Sanibel to Tortugas region (Fig. 11) but has fluctuated somewhat in the Apalachicola region (Fig. 10).

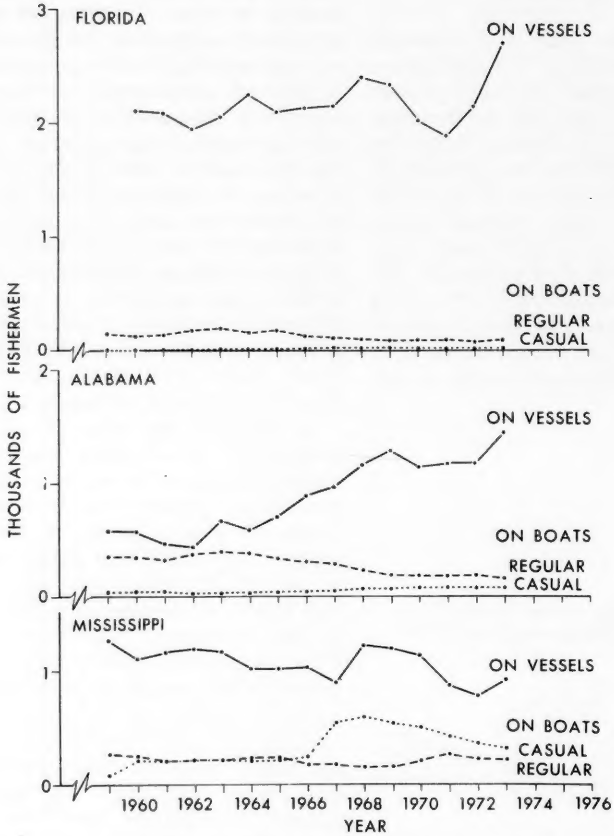


Figure 7—Reported annual number (thousands) of fishermen who shrimped on vessels (5 net registry tons or larger) and boats (less than 5 net registry tons) in Mississippi, Alabama, and Florida west coast, 1959-73.

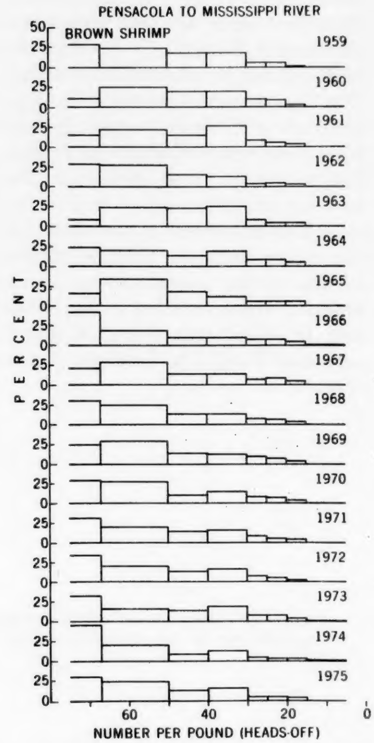


Figure 8.—Count (number per pound, heads-off) composition (percent by weight) of reported annual catches of brown shrimp from the Pensacola to Mississippi River region (statistical areas 10-12), 1959-75.

Estimated ex-vessel value of the reported annual catches is plotted against weight of the catches in Figures 12-15. The points fell remarkably close to the fitted lines, as was the case for brown and white shrimp in the Texas coast and Mississippi River to Texas regions (Caillouet and Patella, 1978). The estimated average ex-vessel values are given in Table 1 along with those from Caillouet and Patella for comparison.

Because they were harvested at larger sizes, brown shrimp in the Texas coast region had the highest estimated average ex-vessel value of $2.22 per pound (in 1975 units). This was

Table 1.—Estimated average ex-vessel value per pound (heads-off, in 1975 units) of brown, white, and pink shrimp from five Gulf Coast States regions, 1959-75.

Region	Brown shrimp (dollars/pound)	White shrimp (dollars/pound)	Pink shrimp (dollars/pound)
Texas coast[1]	2.22	2.07	—
Mississippi River to Texas[1]	1.36	1.75	—
Pensacola to Mississippi River	1.55	1.97	—
Apalachicola	—	—	1.52
Sanibel to Tortugas	—	—	1.56

[1]Adapted from Caillouet and Patella (1978.)

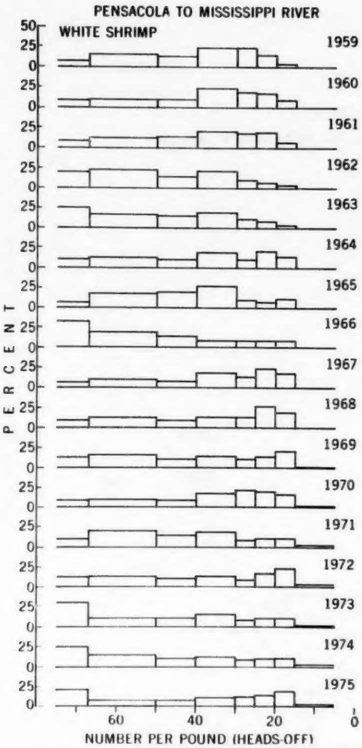


Figure 9.—Count (number per pound, heads-off) composition (percent by weight) of reported annual catches of white shrimp from the Pensacola to Mississippi River region (statistical areas 10-12), 1959-75.

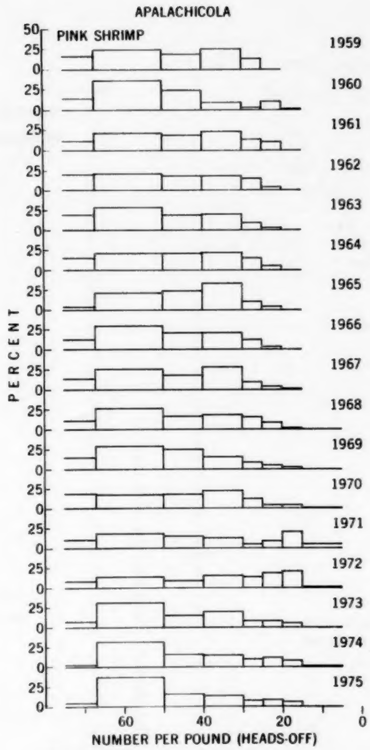


Figure 10.—Count (number per pound, heads-off) composition (percent by weight) of reported annual catches of pink shrimp from the Apalachicola region (statistical areas 7-9), 1959-75.

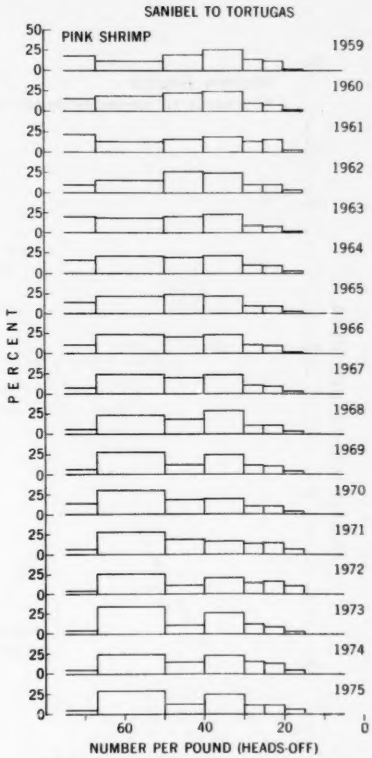


Figure 11.—Count (number per pound, heads-off) composition (percent by weight) of reported annual catches of pink shrimp from the Sanibel to Tortugas region (statistical areas 1-6), 1959-75.

followed, in descending order, by white shrimp in the Texas coast ($2.07), Pensacola to Mississippi River ($1.97), and Mississippi River to Texas ($1.75) regions. Brown shrimp in the Pensacola to Mississippi River region ($1.55) and pink shrimp in Apalachicola ($1.52) and Sanibel to Tortugas ($1.56) were close in estimated average ex-vessel value. The lowest estimated average ex-vessel value ($1.36) was obtained from brown shrimp in the Mississippi River to Texas region.

Management Implications

This paper and that of Caillouet and Patella (1978) use the relationship between estimated ex-vessel value of reported annual shrimp catches and weight of these catches to show the effects of regional differences in count composition of these catches, a function of differences in shrimp laws and harvesting strategy. It seems clear that the strategy of harvest of large proportions of larger shrimp in Texas increases both the weight and ex-vessel value of these catches. Social impacts and economic inputs beyond the ex-vessel level also require consideration in studies of effects of harvesting strategy.

The relationship between estimated ex-vessel value and weight of reported annual catches of a given species in a given region holds remarkably well over a wide range of fluctuations in reported annual catches. In fisheries, such as shrimp fisheries of the Gulf of Mexico, in which wide fluctuations occur in annual yield in response to fluctuations in recruitment, the best that can be done is to make the best use of whatever recruitment occurs (Gulland and Boerema, 1973). This lends support to the concept of management of shrimp fisheries by minimum size limits or other approaches which regulate the size of shrimp at first harvest, i.e., closed areas or seasons. These approaches to management have been widely used in shrimp fisheries of the Gulf of Mexico (Christmas and Etzold, 1977).

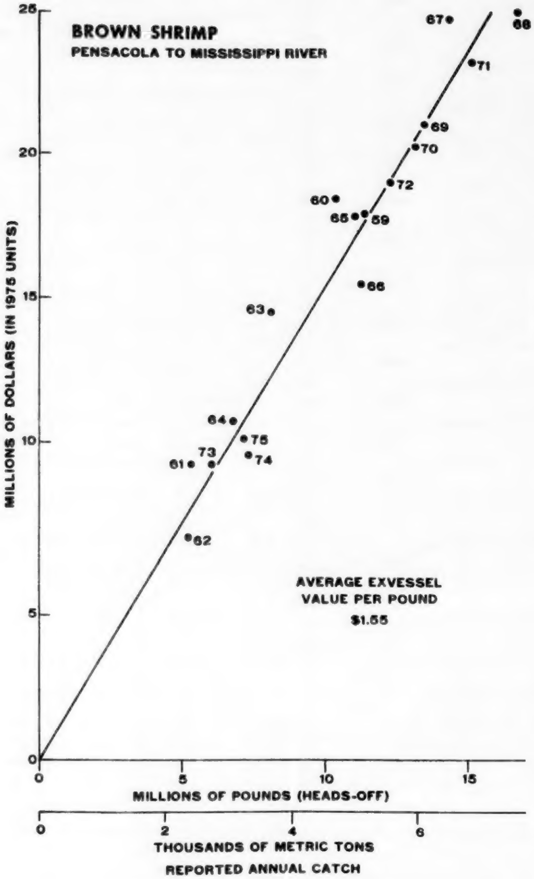


Figure 12.—Relationship between estimated ex-vessel value (millions of dollars in 1975 units) of reported annual catches (millions of pounds or thousands of metric tons, heads-off) of brown shrimp from the Pensacola to Mississippi River region (statistical areas 10-12), 1959-75.

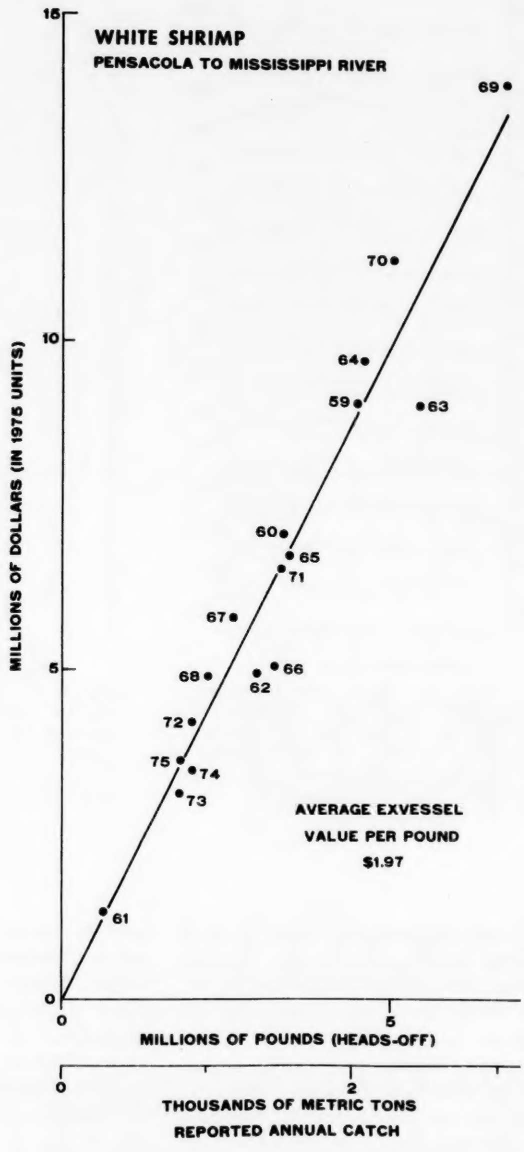


Figure 13.—Relationship between estimated ex-vessel value (millions of dollars in 1975 units) of reported annual catches (millions of pounds or thousands of metric tons, heads-off) of white shrimp from the Pensacola to Mississippi River region (statistical areas 10-12), 1959-75.

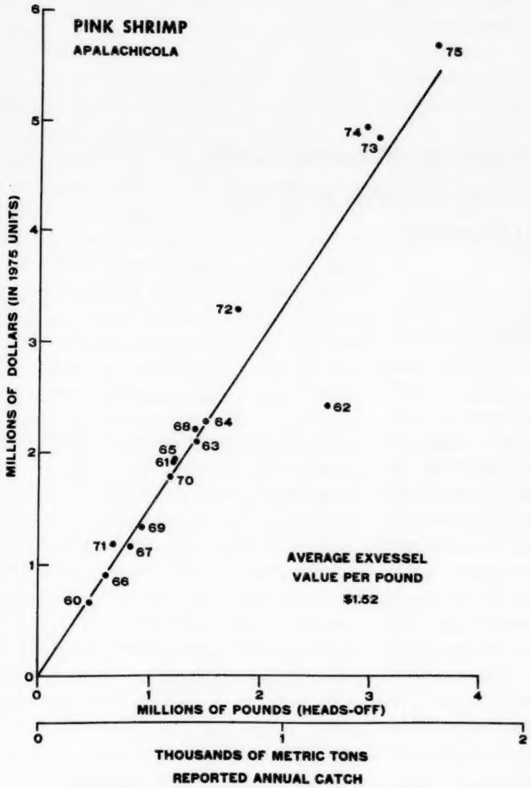


Figure 14.—Relationship between estimated ex-vessel value (millions of dollars in 1975 units) of reported annual catches (millions of pounds or thousands of metric tons, heads-off) of pink shrimp from the Apalachicola region (statistical areas 7-9), 1959-75.

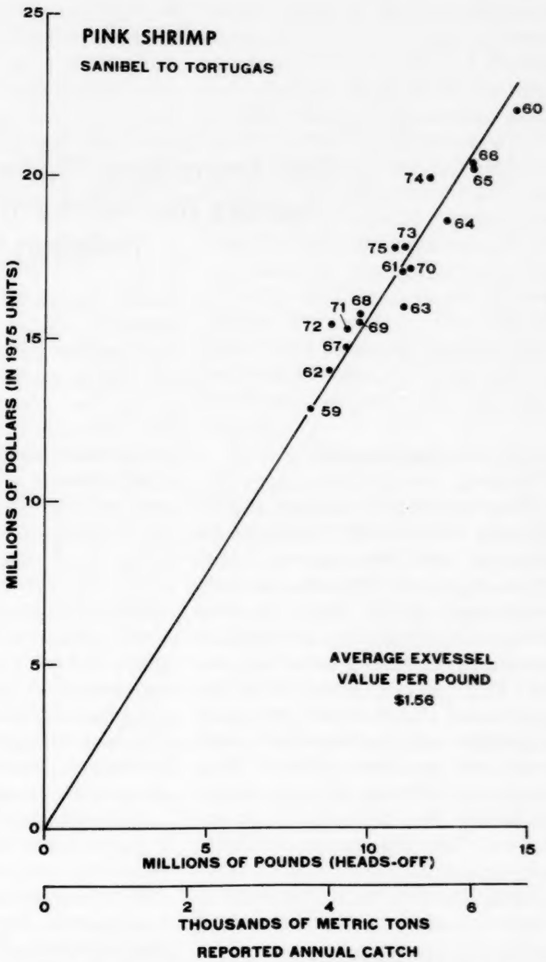


Figure 15.—Relationship between estimated ex-vessel value (millions of dollars in 1975 units) of reported annual catches (millions of pounds or thousands of metric tons, heads-off) of pink shrimp from the Sanibel to Tortugas region (statistical areas 1-6), 1959-75.

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The Anomalous Surface Salinity Minima Area Across the Northern Gulf of Alaska and Its Relation to Fisheries

W. J. INGRAHAM, Jr.

Introduction

The number of oceanographic activities in the Pacific Northwest has increased and there appears to be ample support of field activites in the northeastern Pacific Ocean for these groups. Although oceanographic studies by fisheries groups have not been a part of this increase, they have contributed a considerable amount of knowledge of environmental conditions and processes affecting living marine resources in this area. Recent studies by the NMFS Northwest and Alaska Fisheries Center (NWAFC) provide unprecedented insight into sea surface conditions in the Gulf of Alaska.

Background

The accumulation of knowledge of the marine environment in the Gulf of Alaska has been painfully slow and aperiodic. In the 237 years since the first arrival of "westerners" Bering and Chirikof in the Gulf of Alaska, there have been several significant periods of marine investigations in the Gulf of Alaska prior to current inshore studies supported by Bureau of Land Management funding of NOAA's Outer Continental Shelf Environmental Assessment Program (OCSEAP).

For 126 years the area was under the control of the Russian-America Company when numerous voyages of explorations and exploitation of natural resources (mainly marine mammals) occurred. For nearly 50 years, Russian officials controlled the port of New Archangel (now Sitka) and extensive traffic occurred not only from the Yukon River to southern California, but to various ports of the world (Chevigny, 1965). Much of the local oceanographic knowledge that stems from this period was compiled into the first Alaska Coast Pilot. Davidson (1869) reported that a 0.5-to 1.5- knot current was believed to flow northward, westward, and southwestward along the gulf coast.

Near the end of the 19th century and in the early part of this century, a series of cruises was conducted using the steamer *Albatross* of the U.S. Fish Commission. The location and general characteristics of the various offshore banks along the continental shelf were defined; sea surface and bottom temperatures were obtained. During this period it was generally accepted that water in the gulf originated from the Kuroshio or Japanese Current because of an analogous warming effect the Gulf Stream had on northern Europe. In fact, the Kuroshio was also believed to penetrate Norton Sound in the Bering Sea because of the warm summer temperatures encountered there also.

Extensive investigations in the northern gulf were conducted by the International Fisheries Commission (IFC) from 1927 to 1934. Winter data from only three lines of stations off Ocean Cape, Cape Cleare, and Cape Chiniak revealed a pronounced westward current at the edge of the continental shelf with surface flow as high as 55 cm/second; a marked eastward flow occurred immediately shoreward of this current, but flow over the shelf was generally weak and variable. Also at the shelf edge, the cold surface layer was determined to be underlain by a deeper, warmer stratum (McEwen et al., 1930; Thompson and Van Cleve, 1936), an indication of winter overturn recognized today as a major process in the surface layer.

The possible individual roles of and interactions between the atmospheric Aleutian low pressure system and the Eastern Pacific high pressure system on surface flow were recognized, and extensive drift bottle experiments were conducted across the gulf and seaward of Vancouver Island. The implied trajectories of the bottles indicated a broad sweep of cyclonic flow over the continental shelf with a strong onshore component around the entire gulf. However, the source of this flow was still considered to be the Japanese (Kuroshio) Current (Thompson and Van Cleve, 1936) until the transpacific, largely locally formed, Subarctic Water Mass was identified by Sverdrup et al. (1942).

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During 1950-52, the Pacific Oceanographic Group of the Fisheries Research Board of Canada conducted four offshore oceanographic cruises from the southern end of Vancouver Island to the northern end of the Queen Charlotte Islands in an attempt to define the role of this area in relation to the oceanography of the northeast Pacific Ocean and to define subsystems within the Subarctic Water Mass. Doe (1955) showed the continuity and broad offshore extent of coastal and offshore water masses in the eastern and northern parts of the gulf and (on the basis of data from only a few stations) indicated that these water masses narrowed considerably along the western side of the gulf, suggesting the presence of a boundary current. Seaward of the offshore water mass a rather vague outline of a mid-gulf water mass was presented, defined by a few widely spaced stations obtained aboard the U.S. Coast Guard vessel *Ogalala* in 1936 subsequent to the IFC studies. Thus, only 20 years ago, the nature of the southwest flow out of the Gulf of Alaska and conditions in the mid-gulf area (other than at the surface) could be ascertained from the limited data at several oceanographic stations.

INPFC Studies

Our present concept of the physical environment of the Gulf of Alaska stems largely from the extensive oceanographic studies conducted under the supervision of the International North Pacific Fisheries Commission (INPFC) from 1953 and continuing in varying scope and intensity up to the present. These and other concurrent studies, such as the North Pacific Expedition (NORPAC) in 1955, provided the extensive data required to show the transpacific continuity of flow into the gulf and the origin of local water properties.

Summaries of oceanic environmental conditions from 1953 to 1959 (Dodimead et al., 1963) and from 1960 to 1971 (Favorite et al., 1976) and of conditions in the Gulf of Alaska (Ingraham et al.[1]) form the basis of much of our current knowledge of oceanic conditions. There is a greatly increasing body of information concerning physical conditions in the coastal regime at the head of the gulf as a result of OCSEAP and other studies (e.g., Royer, 1975; Royer and Muench, 1977; Muench et al., 1978; and others).

General Conditions

Changes in environmental conditions in the Gulf of Alaska are largely characterized by water temperature and salinity—the former largely reflects cycles of warming and cooling characteristic of high latitudes and results in relatively uniform conditions over large areas except in coastal regimes where snowmelt and tidal mixing results in lower values than in offshore areas; whereas, the latter largely reflects imbalances between evaporation and precipitation as well as seaward discharges of snowmelt and runoff from the coast and mountain ranges ringing the gulf that result in marked seaward gradients and contribute to a salinity maxima area in the central part of the gulf. The general nature of the permanent flow is cyclonic (counterclockwise) and, as coastal dilution in spring from the eastern side moves seaward, it is advected slowly northward around the gulf. During summer this offshore flow of dilute water in the eastern gulf is further altered by local northwesterly winds which cause an Ekman transport 90° to the right of the wind. These seaward intrusions were detected by Favorite (1961), Dodimead et al. (1963), and others, who reported offshore continuity of coastal plumes of dilute water in excess of several hundred kilometers along the northeast Pacific coast.

Sea Surface Studies

During a NWAFC oceanographic cruise aboard the NOAA research vessel *George B. Kelez* conducted in spring 1972 to ascertain environmental conditions in the vicinity of Portlock and Albatross Banks south and east of Kodiak Island in the western gulf, a band of surface salinity minima (<32.5 ‰) of unknown origin was discovered along a 500 km stretch generally paralleling the edge of the continental shelf (Favorite and Ingraham, 1977). It was assumed that this feature was probably continuous to the eastward around the head of the gulf and marked the boundary between coastal and oceanic water and could serve as a guidepost or path for migrating salmon.

A U.S.-Poland cooperative fishing-oceanographic survey aboard the Polish research vessel *Profesor Siedlecki* in July 1977 provided an opportunity to trace the band of salinity minima eastward. Data from a rather extensive grid of stations clearly indicated a marked separation at the eastern side of the gulf of surface water of salinity <32‰ near lat. 58°30′N, long. 138°30′W (Fig. 1)—one branch extending northwestward along the coast over the shelf, and the other an offshore intrusion that protruded westward across the gulf as a band of offshore salinity minima. The latter was the first known indication of the existence of an offshore band of salinity minimum in this area.

At the head of the gulf, this offshore band was clearly separated from the extensive dilution caused by the runoff from the Copper River, one of the five largest gauged rivers in Alaska and the only one of the five that discharges into the Gulf of Alaska; with an average annual discharge of 8.3×10^6 cfs/year, it ranks third (Yukon, 62.3×10^6; Kuskokwim, 16.4×10^6; Kvichak, 6.4×10^6; Kuzitrin, 4.4×10^6)[2].

[1]Ingraham, W. J., Jr., A. Bakun, and F. Favorite. 1976. Physical oceanography of the Gulf of Alaska. NMFS Northwest and Alaska Fisheries Center, Seattle, Wash., Processed Rep., 132 p.

[2]Seifert, R., and D. Kane. 1977. Effects of seasonability and variability of streamflow on nearshore coastal areas. *In* Environmental assessment of the Alaskan Continental Shelf, annual reports of principal investigators for the year ending March 1977, Vol. 14, Transport, p. 96-250. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin. and U.S. Dep. Inter., Bur. Land Manage., Boulder, Colo.

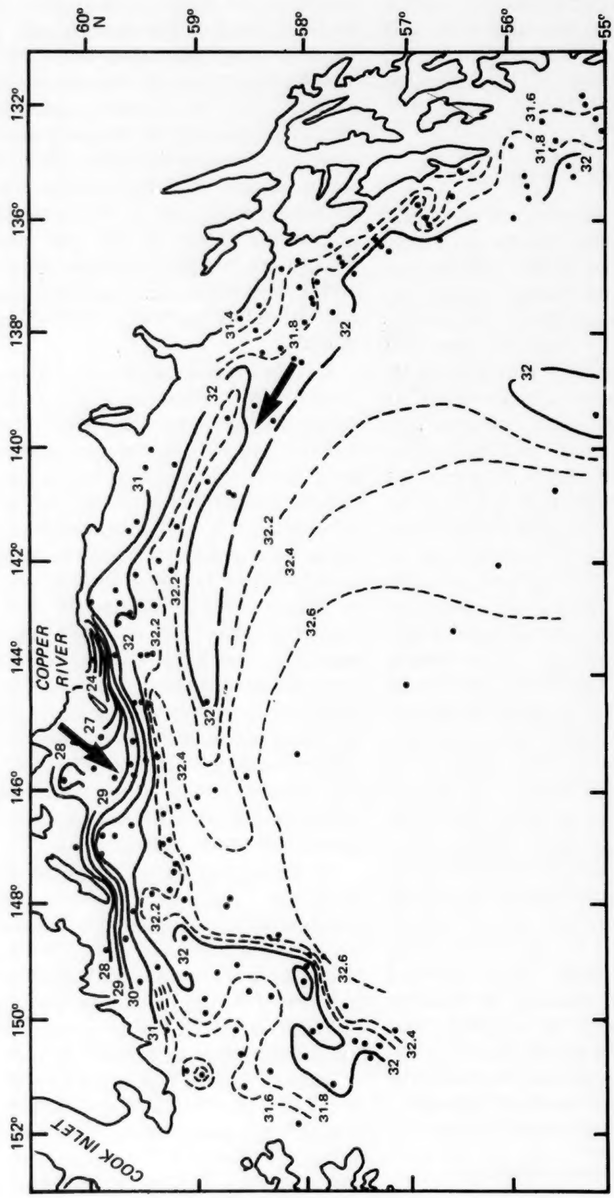

Figure 1.—Surface salinity (‰) taken from the Polish RV *Profesor Siedlecki*, 4-31 July 1977, and stations where salinity data were obtained. Arrows indicate the probable direction of movement of the major sources of dilution into the offshore area.

Although a mean daily discharge of approximately 10,000 cfs usually occurs from November to April, values of over 100,000 cfs may occur by June and continue into September. Thus, the *Profesor Siedlecki* data in July 1977, reflect only the initial stages of the annual discharge of Copper River water into the oceanic regime. This separation of dilute surface water in the eastern gulf is significant because it could determine whether fish eggs and larvae along the continental shelf and slope in this area would either be carried offshore or confined inshore; whereas, in the northern and western gulf planktonic forms over the shelf and slope would be confined entirely inshore.

The western gulf may be even more significant as a mixing zone of the minima caused by the Copper River plume and the offshore salinity minima area as they merge and flow southwestward out of the gulf. Thus, at any specific time or specific location either source may dominate. Unfortunately, the *Profesor Siedlecki* data are not adequate to detect the extension of the offshore salinity minima to the western side of the gulf, but fragmentary portions of one or both minima are evident in some data from OCSEAP cruises conducted off Kodiak Island during 1977. An area of salinity minima near the shelf edge was well defined in March with values < 32.0-32.2‰ (much lower than in May 1972), detectable in July, and strongly evident in September as a pronounced offshore minima area with values < 31.8‰.

During October the minima area was poorly defined as salinities increased slightly, but by November it became more pronounced as the salinities over some of the shallower banks at midshelf increased as a result of winter mixing and turnover. Thus, east of Kodiak Island the salinity minima occurs year-round and cannot be attributed to a single local, seasonal coastal source of runoff, for example, the Copper River—but a combination of local and trans-gulf sources.

The area of low salinity detected at lat. 55°-56° N, long. 139° W during the *Profesor Siedlicki* cruise (Fig. 1) suggests another source. The low salinity values in this area are believed to originate from seaward discharge in spring of coastal water out of Dixon Entrance (lat. 54° 30′N) and/or Queen Charlotte Sound (lat. 51°-52° N). Favorite (1961) has shown that such plumes reach to at least long. 137° W.

The increased data coverage in 1977 thus provided knowledge of the seasonal complexities in the continuity of surface salinities which, although subject to mixing and stirring, reflect surface water movement. With this background, plans were made to take an opportunistic look at as much of the area as possible in summer 1978 during a NWAFC fishing cruise aboard the NOAA research vessel *Miller Freeman* in August-September. As a result of a meeting at the NWAFC on 13 July 1978, with scientists from the Korean Fisheries Research and Development Agency who were about to conduct operations in the northern gulf aboard the Korean research vessel *Oh Dae San*, a cooperative plan to obtain surface salinities was approved. Surface water samples obtained in the northern gulf during August from aboard the *Oh Dae San* would be discharged at Kodiak for analysis by NWAFC personnel when the *Miller Freeman* reached Kodiak in September. Subsequently a salinograph unit was installed aboard the *Miller Freeman* during an August 1978 port call in Seattle in order to obtain a continuous record of surface salinity along cruise tracks normal to the coast at the head of the gulf.

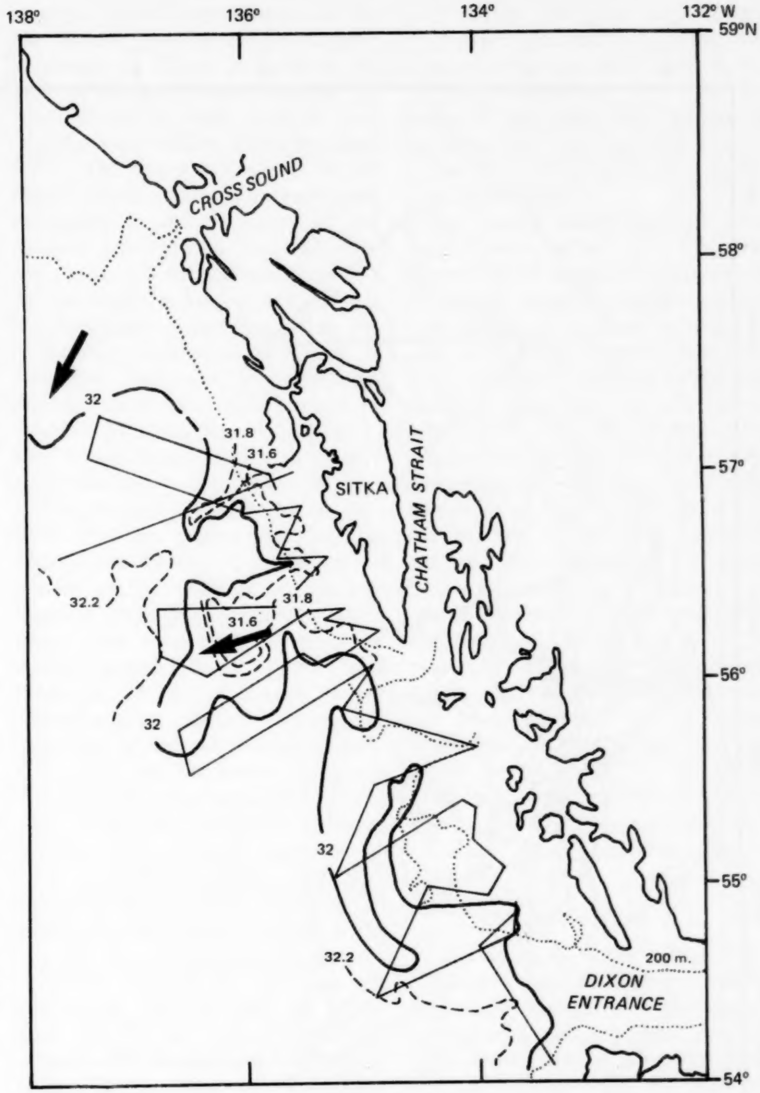

Figure 2.—Surface salinity (‰) taken from NOAA RV *Miller Freeman*, 25-30 August 1978, and cruise tracks along which continuous salinity measurements were made. Arrows indicate the probable direction of movement of the major sources of dilution into the offshore area.

Because this study aboard the *Miller Freeman* had to be a part of a fishing cruise, observations were obtained during two different periods of vessel operations. From 25 to 30 August 1978, the salinograph was operated during hydroacoustic-fishing trawl transects over the shelf during the day and on offshore excursions during the night between Dixon Entrance and Sitka. Surface conditions in this area were quite dilute (Fig. 2) with surface water salinity over the shelf of 31.3-32.0‰ and offshore water from 31.6 to 32.2‰. Considerable complexity, with numerous lenses, offshore tongues, and small scale features was

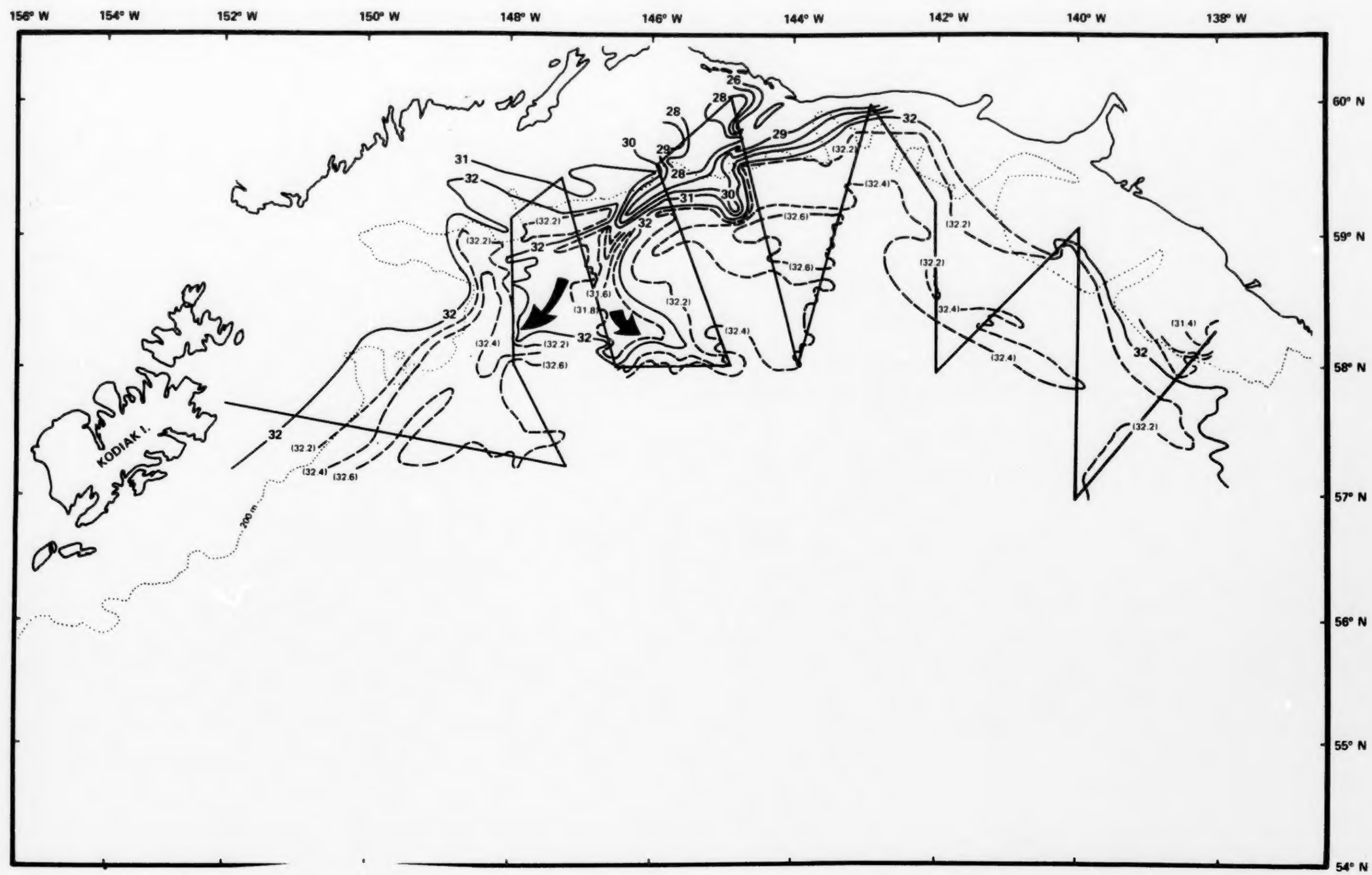

Figure 3.—Surface salinity (‰) taken from NOAA RV *Miller Freeman*, 1-6 September 1978, and cruise track along which continuous salinity measurements were made. Arrow indicates the probable direction of movement of the major sources of dilution into the offshore area.

evident. The predominant features along the southeast coast are the saline offshore water (>32.2‰) and tongues of dilute water (<32.2‰) which protruded as much as 135 km into the oceanic water from two major sources of dilution, Chatham Strait (near lat. 56°N) and Cross Sound (near lat. 58°N).

Much small detail is evident by the continuous sampling in the range of 0.1-0.2‰). Offshore minima were present where the seaward tongues were either cut off by mixing or turned with the flow beyond the shelf; but no continuous, alongshelf band of salinity minima was evident. Normal oceanic salinities >32.5‰were not encountered along any of the cruise tracks off southeastern Alaska.

Observations at the head of the gulf, the area of prime interest, were obtained by requesting a 3-day delay in the scheduled arrival of the *Miller Freeman* at Kodiak. Data were obtained from 1 to 6 September 1978 along 2,780 km (1,500 miles) of continuous zig-zag tracklines at a speed of 13 knots as the vessel was enroute (Fig. 3). Hourly water samples were taken and analyzed aboard ship with a precision laboratory salinometer (Autosal[3] 8400) and salinity and temperature values were digitized from the traces by hand to show linear trends and peaks on a 5-15 minute interval (about every 2-6 km). The analysis of these data, probably the most detailed and synoptic surface salinity record for the area, revealed several interesting features.

Along the northeast coast the trend of the isohalines was generally parallel to the shoreline apparently reflecting alongshore processes in the absence of major freshwater sources. The dominant feature is the seaward penetration of the low salinity (31.6‰) plume from the Copper River area extending 80 km south of the shelf break well into the oceanic regime of high salinity (>32.6‰) water.

In July 1977 this plume was confined largely to the shelf area westward of the river mouth. The sharpest frontal zone (a change of 2-4‰) occurred at the head of the gulf; downstream to the southwestward both minima and maxima were evident along the shelf break. The seaward terminus of the plume reflects an anomalous eastward movement in the proximity of the Alaskan Stream, a narrow, high velocity (50 to 100 cm/second) boundary current which is known to flow in a southwesterly direction along the continental slope area. As evident in data from other years, intense mixing and stirring at the surface just east of Kodiak Island (lat. 58°N, long. 148°W) has largely eradicated most of the dilute plume south of lat. 58°N.

Unfortunately vessel-time limitations did not permit steaming far enough into the central portion of the gulf to adequately define the offshore features; however, fortunately, additional data from the University of Alaska research vessel *Acona* and from the NOAA research vessel *Oceanographer* obtained during the same time period, were made available to us (Fig. 4A). The former permitted clarifying distributional patterns at the head of the gulf; the latter provided evidence of a seaward extension of dilute water from the eastern side of the gulf at lat.56°-57°N to long. 143°W where it terminated at a salinity front oriented in a north-south direction.

Normal cyclonic circulation in the gulf would indicate that the dilute water of salinity<32.2‰ should have merged with the eastward component of the Copper River plume by fall. Whether the resulting water mass would eventually move northward to the head of the gulf before turning southwestward or turn westward near lat. 58°N, it is obvious that both sources will contribute to the offshore salinity minima east of Kodiak on a year-round basis.

Although surface temperature information is the most readily attainable data base to investigate ocean conditions and anomalies (e.g., the data are easily measured from an instrumentation standpoint, routinely collected by most vessels, and now supplemented by gradient information in cloud-free areas of infrared satellite photos), it is strikingly apparent (Fig. 4B) that neither of these sources of dilution nor the patterns of flow suggested by them are as clearly evident in the temperature distribution.

One feature readily apparent nearshore between lat. 56° and 57°N at the eastern side of the gulf is the colder (2-4°C) water associated with snowmelt and runoff; but, perhaps, more significant is the extensive seaward protrusion of the 14°C isotherm in this area that is similar to the 32.2‰ isohaline. Nevertheless, in the offshore area, there is only about a 1°C change across the entire gulf with the eastern gulf being generally warmer. Further, if one accepts the significance of 0.5°C temperature differences, the warm (>14°C), southward protruding tongue offshore in the northern gulf at long. 146°W, which occurs at the eastern side of the area of the offshore salinity minima, appears to support the idea of an eastward flow of Copper River dilution near lat. 58°N as suggested earlier. Finally, the possibility of the trans-gulf band of 14°C water near lat. 58°30′N being a harbinger of a trans-gulf salinity minima band is intriguing.

Discussion

The question of the existence and nature of the offshore salinity minima area across the head of the gulf and the mixing and merging area near lat. 58°N at the western side of the gulf is not completely resolved and will require more intensive observations along even more closely spaced tracklines and repeated surveys from month to month. Certainly the data presented indicate that the offshore salinity minima area eastward of Kodiak Island represents a convergence of surface water from two distinct sources but at times only one of these sources may be represented.

Now that presence of this surface feature has been clearly established, it is easy to find evidence of it in previous

[3]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

data, which in most cases were too fragmentary to justify assuming the extensive continuity that apparently exists. (It should be pointed out that such data were obtained largely to define large-scale features of oceanic circulations in the eastern Pacific Ocean.) For example, data for 19 July to 11 August 1958[4] (Fig. 5) reflect surface salinity minima in several lines of data normal to the coast at the head of the gulf that is not evident on the map of surface salinity presented in Dodimead et at. (1963:133) because of isoline intervals and map scale. Further, this feature can also now be detected in data for 22 May to 10 June 1961[5] off Kodiak Island and other more fragmentary data sources. Although the overall patterns of surface salinity are markedly different, the presence of the band of offshore salinity minima is readily apparent.

A schematic of the effect of the annual cycle of dilution is presented with likely locations by season of the extent of dilute water (Fig. 6). During spring the initial movement offshore occurs at sites of extensive runoff. In summer, spring dilution has extended farther offshore in the eastern gulf with some contributions from the south. By fall, runoff sources are diminishing with the advent of freezing, and dilution that entered the area from the southeast is traversing the gulf, while spring and summer dilution from the eastern gulf has reached the eastern Kodiak mixing area. Here, overturn and mixing produce high salinities on the shallow shelf areas—thus the offshelf minimum is most pronounced.

Finally, in winter there are no major sources other than a general area

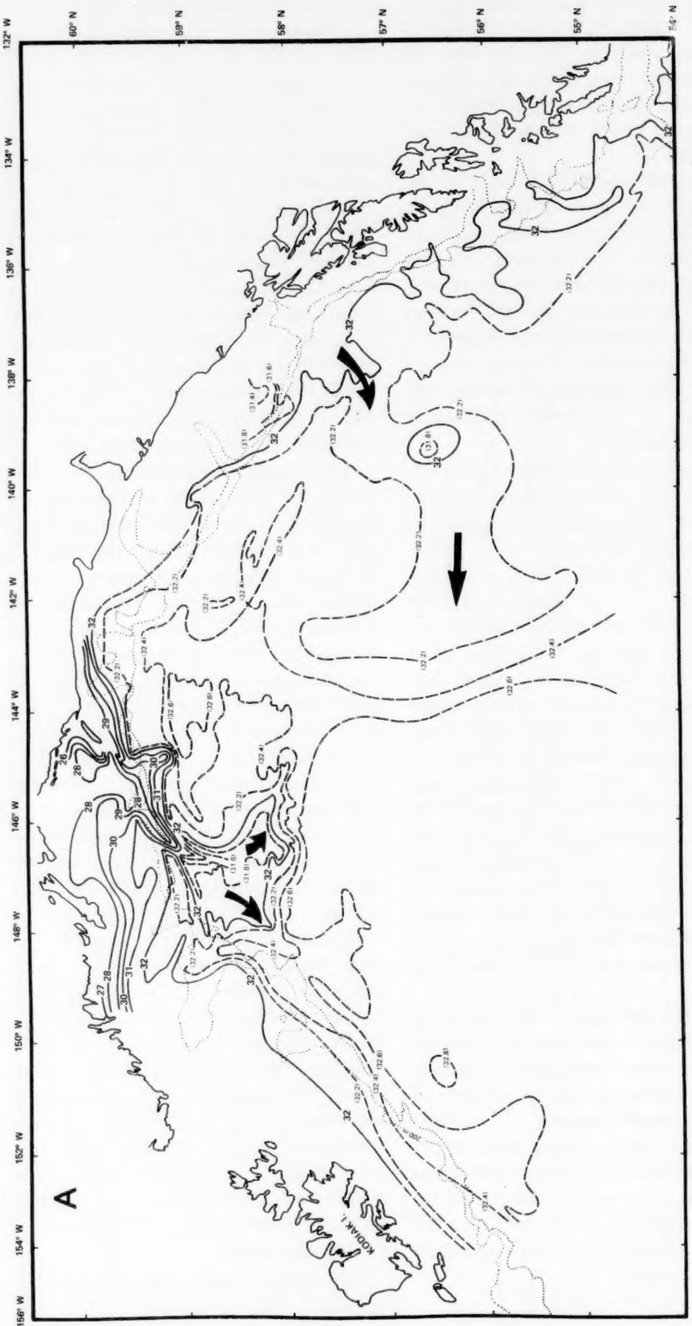

Figure 4A.—Surface salinity (‰) taken from NOAA RV *Miller Freeman*, 25 August-6 September 1978, and stations where data from the University of Alaska RV *Acona*, Korean RV *Oh Dae San*, and NOAA RV *Oceanographer* were obtained. Arrows indicate the probable direction of movement of the major sources of dilution into the offshore area.

[4]Pacific Oceanographic Group. 1958. Physical and chemical data record North Pacific surveys continental shelf and Gulf of Alaska July 22 to August 16, 1958. Fish. Res. Board Can., Manuscr. Rep. Ser., Oceanogr. Limnol. 29, 107 p. + append.

[5]Dodimead, A. J., F. M. Boyce, N. K. Chippendale, and H. J. Hollister. 1961. Oceanographic data record North Pacific surveys May 16 to July 1, 1961. Fish. Res. Board Can., Manuscr. Rep. Ser., Oceanogr. Limnol. 101, 337 p.

contribution from precipitation at sea which is not considered. Mixing is increased both vertically and horizontally but spring and summer dilution from the eastern side of the gulf is still sufficient to maintain a remnant of the trans-gulf salinity minima area. This suggests year-round convergence in the offshore band of salinity minima and divergence in the band of salinity maxima that occurs shoreward of the minima at the head of the gulf.

Relations to Fisheries

For over half a century fishery biologists have been trying to ascertain how Pacific salmon, *Oncorhynchus* spp., find their way in the ocean. Although the extensive INPFC studies have fairly well documented the oceanic distribution of various species, little is known about seaward migrations of smolts or shoreward migrations of adults. The available evidence indicates that the seaward migration path of nearly a billion juvenile sockeye salmon, *O. nerka*, in the Vancouver Island-Queen Charlotte Sound area is northward along the coast and around the Gulf of Alaska to the Kodiak Island area, where they diffuse into the oceanic regime.

Since downstream migrations occur as snowmelt and runoff commence or peak, it is reasonable to assume that salmon, particularly the sockeye, could have some affinity to river plumes and remain within their influence as long as possible. This would suggest that seaward migrants from the above area move offshore and into the central gulf south of southeastern Alaska, thereby avoiding not only the necessity of intermingling with stocks in the northern areas, but also the encounter of seaward discharges and associated water characteristics of innumerable other coastal streams.

Perhaps most significant is the fact that such a migration path would serve to isolate these salmon from the juvenile sockeye salmon from the Copper River until the latter had entered the oceanic regime.

Keys to shoreward migrations are

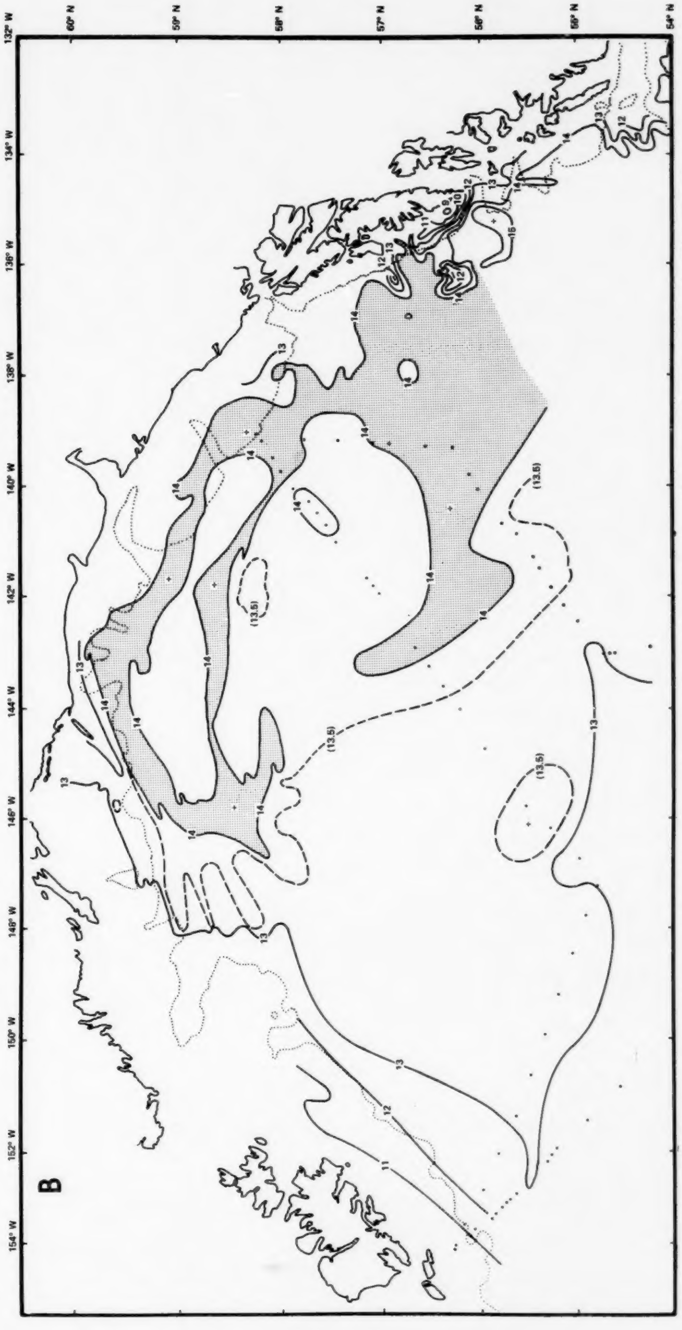

Figure 4B.—Surface temperature (°C) taken from NOAA RV *Miller Freeman*, 25 August-6 September 1978, and stations where data from the University of Alaska RV *Acona*, Korean RV *Oh Dae San*, and NOAA RV *Oceanographer* were obtained.

complex because widespread ocean migratons involve environmental considerations from a wider area than considered here; however, the data presented here indicate for the first time that salmon returning to the Copper River can find strong clues to the river discharge over 200 km seaward of the river mouth. As a result of this, studies on the oceanic distribution and migration of salmon in this area should no longer be undertaken without extensive knowledge as to immediate location of seaward extensions of coastal or river plumes.

Obviously it is difficult to relate surface phenomenon to behavior of groundfish, although it can be shown that surface manifestations of subsurface flows are common, i.e., upwelling wherein offshore transport of surface water by winds requires replenishment of mass from subsurface water along the coast. This causes an inshore flow at some point along the sea floor that is subsequently readily apparent at the surface in lower sea surface temperatures. However, those species of bottomfish having pelagic eggs and larvae can be greatly affected by surface conditions.

Pacific halibut, *Hippoglossus stenolepis,* for example, have two known major spawning grounds: 1)South of Queen Charlotte Island, and 2)off Yakutat. Eggs deposited off the shelf at depth, 200 m or greater, in winter rise to the surface layer in spring. Larvae, whose survival is dependent on settling out of the water column in coastal areas, are at the mercy of surface currents during spring and summer.

Heretofore, it has been assumed that the general surface winds and cyclonic flow in the gulf have provided mechanisms wherein surface transport along the coast has been shoreward, thereby contributirg to, if not responsible for, the successful survival of halibut larvae. Obviously evidence presented here indicate some mechanisms that are not conducive to the

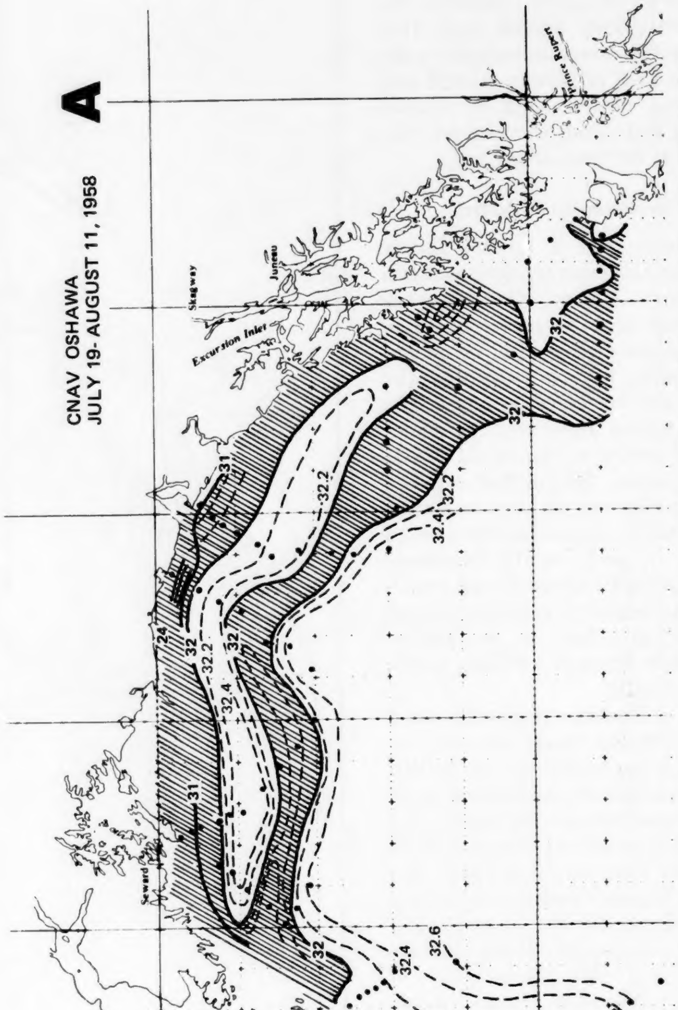

Figure 5A.—Surface salinity (‰) taken from Canadian RV *Oshawa,* 19 July-11 August 1958, and stations where salinity data were obtained.

survival of the larvae and must be considered in any study of this species, or other groundfish species with similar early life stages. One can easily extend these remarks to concur as to the ultimate fate of larvae of decapods such as king crab, *Paralithodes camtschatica,* and snow crab, *Chionoecetes* spp., and pandalid shrimp which are also abundant along this stretch of coastline.

Finally, it should be obvious that any hydrodynamic-numerical or other circulation or water transport models developed by OCSEAP and other groups to forecast or to ascertain the ultimate fate of pollutants from potential oil drilling sites in this area, must include aspects of all the conditions and processes associated with the year-round occurrence and variability of this phenomenon.

Acknowledgments

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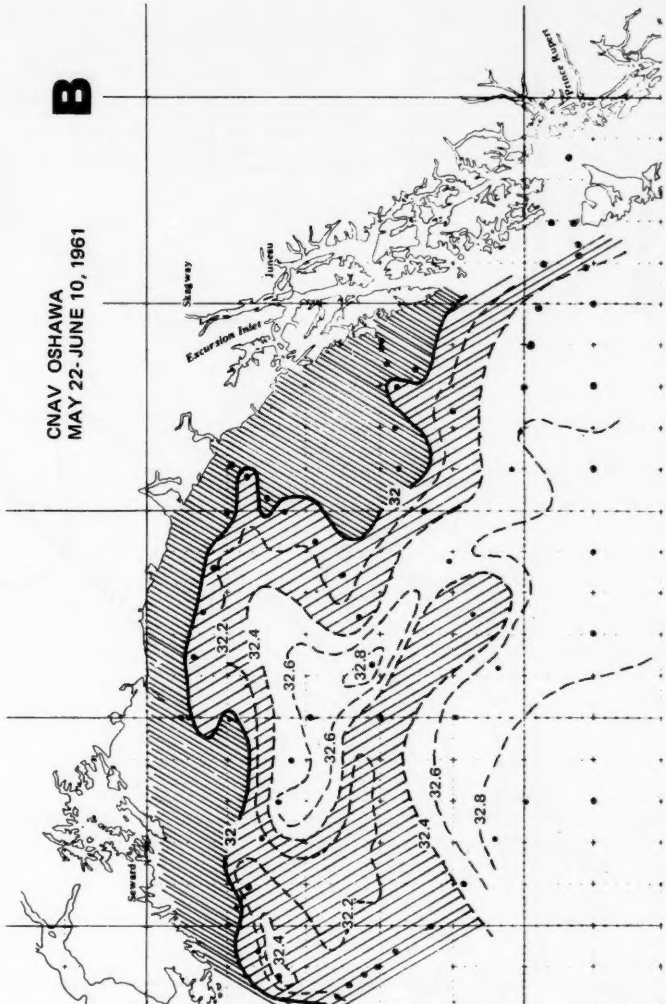

Figure 5B.—Surface (‰) taken from Canadian RV *Oshawa,* 22 May-10 June 1961, and stations where salinity data were obtained.

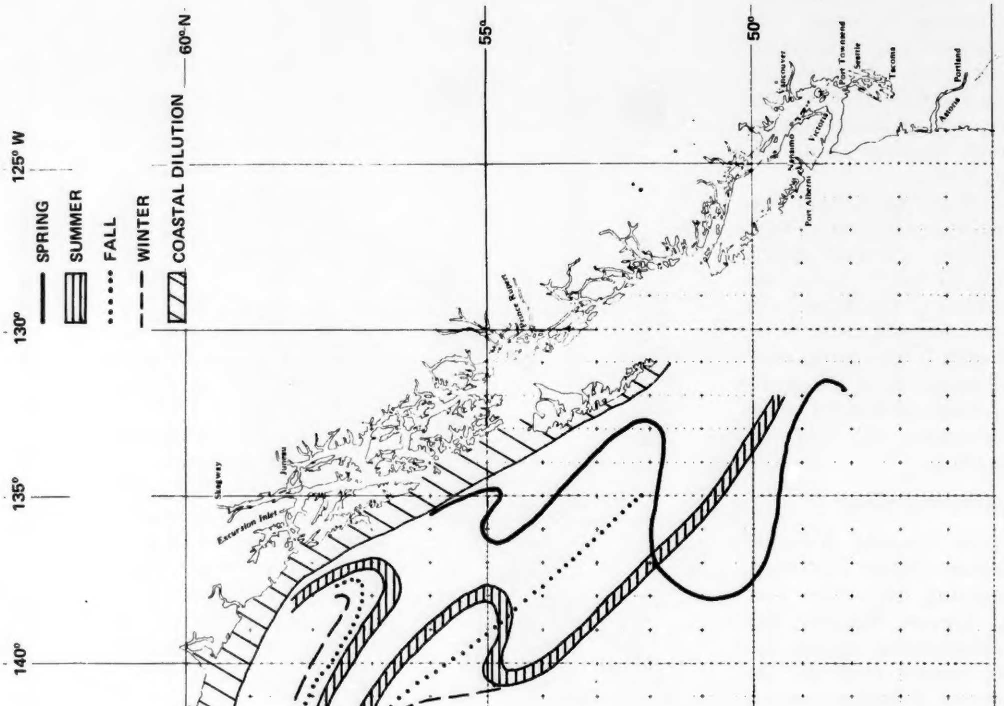

Figure 6.—Schematic diagram of the seaward extent of the major effects of coastal dilution by season.

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Atmospheric Climatology and Its Effect on Sea Surface Temperature—Winter 1977 to Winter 1978

ROBERT R. DICKSON and JEROME NAMIAS

The previous report in this series (Dickson and Namias, In press) has described the progressive amplification of the Northern Hemisphere circulation in 1976 compared with the abnormally strong westerly flow of the preceding 5 years. In 1977 this amplified circulation type was maintained, characterized in addition by episodes of extreme circulation anomaly and by elements of great persistence.

All three of these characteristics—high amplitude flow, extreme abnormality, and tenacious persistence—were displayed during winter 1976-77. The mean distribution of 700 mb height anomaly for winter (Fig. 1A) leaves little doubt about the strong amplification of planetary waves in the upper westerlies in that season; the principal centers of height anomaly—an intense Pacific trough south of the Aleutians (-520 feet), the meridional ridge overlying the west coast of North America (+250 feet), the deep response trough downstream over eastern North America, and a major ridge (not shown) over northern Siberia—all represented departures of three standard deviations or more from the long term seasonal "normal."

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As Wagner (1978) pointed out, such intense abnormalities are unlikely to occur in a given location more than once per century. The dislocating effect on climate in this sector (including record breaking cold over eastern North America) was compounded by the extreme persistence of these cells. Since their establishment in fall 1976, the major troughs and ridges intensified but showed little change in position through most of the succeeding winter. Of the changes which did occur between fall and winter the principal feature was the establishment of an immense blocking high over the polar region in early January, encouraging a southward displacement of the zonal westerlies over much of the hemisphere which amounted to a record expansion of the circumpolar vortex (Angell and Korshover, 1978).

Figure 2 illustrates the resulting sympathetic shift in the principal storm track over the Atlantic sector by showing the total (3-month) change in winter storm activity from the previous winter (1975-76) to the winter under discussion. As shown, storm activity decreased markedly at high latitudes, principally along a zone connecting the east-central United States, south Greenland, and Iceland where the deficit exceeded 10 storms per season. The main zone of increased storm activity lay further south along the American Atlantic seaboard and eastward to western Europe.

The possible causes of such extreme and protracted climatic behavior have been discussed by Namias (1978). First, it is evident that the anomalous tendencies of the atmospheric circulation during fall and winter were almost completely in phase with the normal trends of seasonal forcing so that underlying seasonal changes did not oppose (and may have amplified) the factors responsible for generating the abnormal windfield. Thus a deep summer trough off the western seaboard and a downstream ridge over central North America, such as were observed in summer 1976, will normally retrogress to the east central Pacific and west coast respectively in fall, and from fall to winter there is normally a tendency for the Pacific trough and the west coast ridge to intensify further in these locations, accompanied by a southward shift of the main westerly wind axis and storm belt. The main point at issue here of course is the reason why these apparently normal tendencies of the circulation were exaggerated into features of extreme anomaly.

The factors at work appear to have included the following. First, retrogression of the high pressure anomaly cell to western North America in fall brought a strong southerly air flow to the eastern Pacific, inhibiting coastal upwelling, reducing the loss of sensible and latent heat to the atmosphere and boosting northward advection of warm water along the western seaboard. As a result, there occurred a progressive and dramatic anomalous warming (or more correctly a lack of normal seasonal cooling) of east Pacific waters from summer 1976 to winter 1976-77, by which time core anomalies off the west coast exceeded +3.5°F (Fig. 1B).

In sharp contrast, a vast zonal tongue of abnormally cold surface water (in places three standard deviations from normal) persisted in the west and central North Pacific, a remnant of the cold water belt of record extent which had prevailed in the summer of 1976 (Namias, 1978). The maintenance of these cold conditions into fall and winter under an intense and persistent Aleutian trough is readily explained by the enhanced cloud cover, increased sensible and

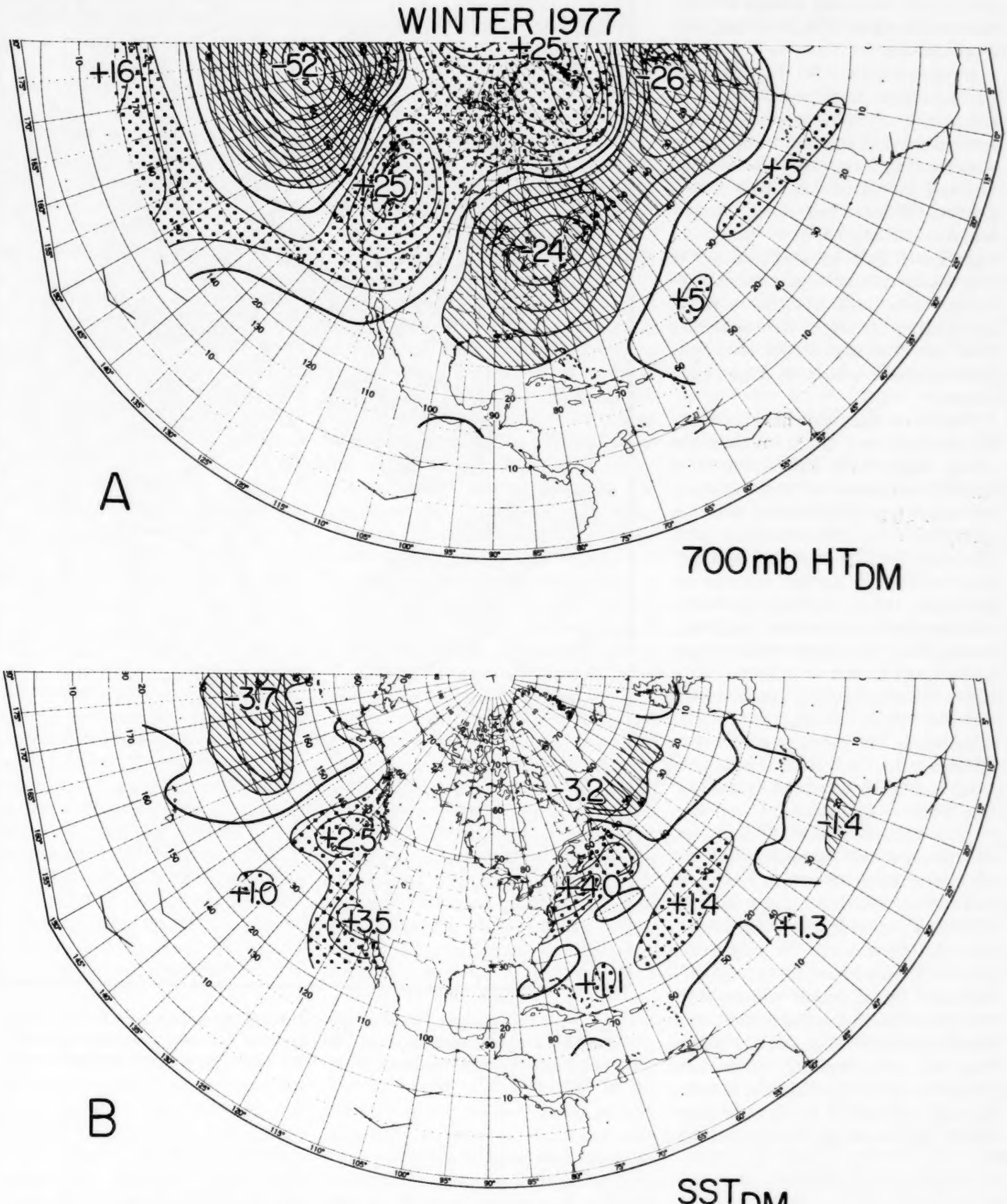


Figure 1.—Mean distribution of (A) 700 mb height anomaly (feet ÷ 10) and (B) sea surface temperature anomaly (°F) for winter 1976-77.

latent heat loss[1], cold frontal activity, and surface water divergence that such a cell implies.

Between these two extremes of Pacific surface temperature anomaly, a sharpening zone of east-west temperature contrast developed from fall to winter along long. 140°-150°W (Fig. 1B) and the baroclinic effect of this gradient (itself extreme) is suggested by Namias (1978) to have played a significant role in stabilizing the anomalous circulation pattern, sharpening frontal and cyclonic activity, augmenting the upper level southerly flow over the east Pacific and thus reinforcing the west coast ridge downstream.

The above discussion has concentrated on only two of the mechanisms which might have lent a degree of stability and persistence to the anomalous circulation of the fall and winter in question (i.e., compatibility with seasonal forcing and the feedback effect of extreme surface temperature gradients). Other possible contributory mechanisms have also been suggested; among these are the possible remote influence of El Niño conditions in the eastern tropical Pacific (present from summer 1976 to spring 1977) in maintaining the intensity of the deep Aleutian low via the mechanism described by Bjerknes (1966) and later simulated by Rowntree (1972, 1975).

Elsewhere, as Namias (1978) indicated, the recurrent outbreaks of Arctic air over eastern North America in the lee of the west coast ridge and the refrigerating effect of the greatly extended snow cover (the most extensive for at least 10 years; Matson, 1977) enhanced the baroclinic contrast at the eastern seaboard, leading to an intensification of east coast storm activity and thus to a reinforcement of the mean trough in this sector also. (In January, during its period of strongest development, upper westerly wind speeds were as much as 8 m/sec above normal off the southern Atlantic coast (Wagner, 1977).) The question as to which of these feedback loops exerted a significant control on the circulation is at present unknown; nevertheless, it is

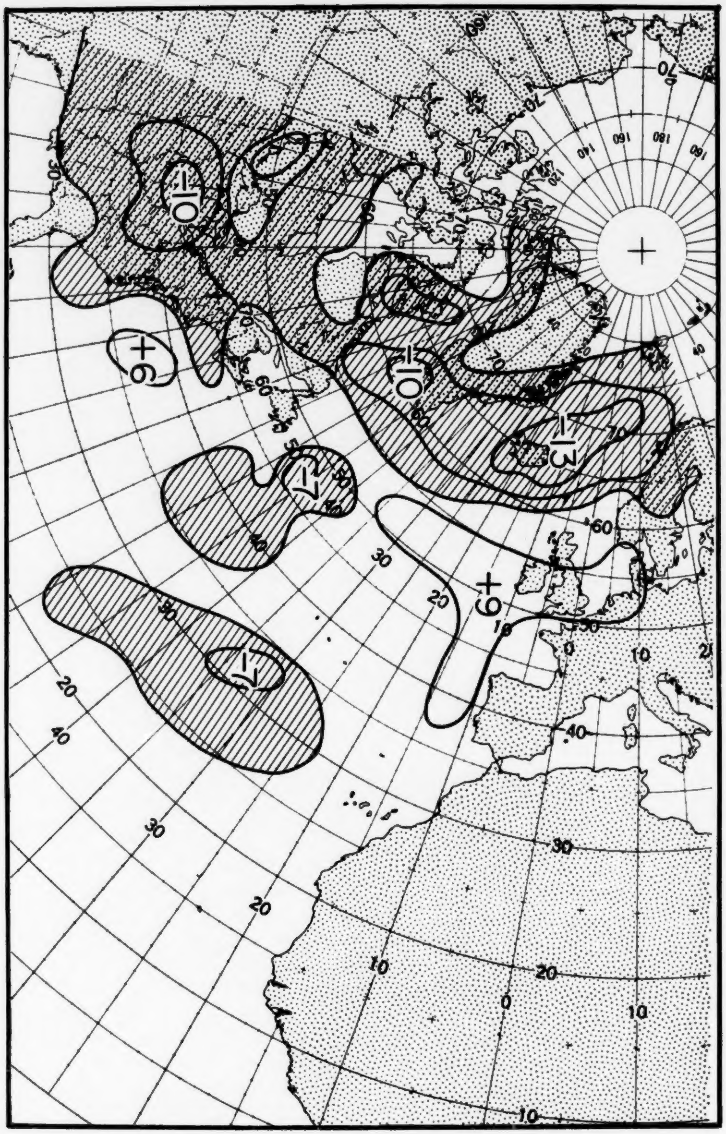


Figure 2.—Change in the total number of storms from winter 1975-76 to winter 1976-77. Contours represent an overall change of 5 or 10 storms per season with areas of decrease shaded. Based on monthly storm track charts published in the *Mariners Weather Log*.

[1]In January, Wagner (1977) reported that the westerlies at 700 mb level were as much as 11 m/sec stronger than normal in the vicinity of the Pacific trough.

hard to avoid the suggestion that acting (as they did) in unison, their combined effect was at least partly responsible for the tenacious persistence of the anomalous circulation through two consecutive seasons.

The effects of this intense and protracted atmospheric forcing on sea surface temperature (SST) over the North Pacific has already been described. In the Atlantic sector (Fig. 1B) the major centers of SST anomaly lay off the Atlantic seaboard where a tongue of abnormally warm water (+4.0°F) followed the axis of the Gulf Stream, and off south Greenland where a broad zone of cold surface water (-3.2°F) extended southward and eastward towards Europe. The former center may not simply be due to the strong southerly circulation around the American coastal trough; Worthington (1977) has presented evidence that intense cold air outbreaks from the American continent in winter may bring about a radical deepening of the thermocline south of the Gulf Stream and hence an intensification of warm water transport by the Gulf Stream system. The cooling in the northern North Atlantic is the expected result of strong anticyclonic circulation over Greenland which tends to occur (as in this case) when a well-developed baroclinic zone at the American Atlantic seaboard encourages a south-eastward shift in the mean position of the Iceland Low (Dickson and Namias, 1976).

The last week of winter finally saw the breakdown of the hemispheric circulation pattern which had dominated the fall and winter seasons but the spring circulation which replaced it displayed features of almost equivalent abnormality. As Figure 3A shows, the circulation anomaly pattern which emerged was almost exactly out of phase with the pattern of the preceding fall and winter over much of the Northern Hemisphere. Centers of positive height anomaly abruptly replaced the preexisting intense troughs over the North Pacific, eastern North America, and western Europe, while a narrow salient of negative height anomaly extended over western North America from a deep trough centered on the Bering Sea. Once established, however, this new planetary wave pattern persisted with almost as much regularity as had the winter pattern. As Wagner (1978) pointed out, such persistence is even more unusual in spring than winter since the "transition season" of spring is characterized by rapid changes in solar angle, in the length of day, and in thermal contrast between continent and ocean.

Although the principal anomaly cells of the spring circulation were considerably less extreme than those of winter (only the Great Lakes ridge approached three standard deviations from normal), the reversed sense of the circulation brought a rapid modification of surface temperature anomalies over both oceans. The elimination of the mean trough from the central North Pacific (coincident with the cessation of El Niño conditions in the tropics), brought a relative change toward less cloudy skies, settling air, surface water convergence, and a slackening of midlatitude westerly flow; as a result the long established cold water tongue in the west Central Pacific was considerably eroded, with core anomalies warming by 1°F compared with winter (Fig. 3B). Off the American west coast where the anomalous temperature field was less well entrenched, the change from anomalous southerly to northerly air flow (Fig. 3A) led to a reversal of the warming processes there (including a resumption of coastal upwelling) and hence to the almost total destruction of the preexisting warmth in the eastern Pacific. Together, these new tendencies towards warming in the west and cooling in the eastern Pacific also brought the virtual elimination of the strong east-west surface temperature gradient which had been an important feature of the winter season. In the Atlantic sector the only center of SST anomaly to persist unaltered into spring was the tongue of anomalous warmth overlying the Gulf Stream axis off the Atlantic seaboard. If real, this center most probably reflects the continued influence of strong Gulf Stream transports initiated by the extreme cold air outbreaks of the winter season. In April the volume transport of 95 sverdrups was the largest value ever computed for the Gulf Stream (Worthington, 1977).

In summer 1977 (Fig. 4A) the hemispheric circulation became progressively less amplified than hitherto with weak tongues and ridges progressing rather rapidly from month to month. In the seasonal mean, however, a zonal belt of below-normal heights extended from south of the Aleutians to eastern Canada and this, coupled with moderate subtropical ridges farther south, gave rise to a flat and fairly fast flow across the North Pacific and along the U.S.-Canadian border (where an active frontal zone with enhanced storm activity developed between the cool Canadian air and the stagnant heat of the South).

In the Pacific sector this enhanced westerly flow maintained (or rather amplified) the cool surface temperatures in the west central region and completed the demolition of the preexisting warmth at the American seaboard so that an unbroken belt of cool surface water now followed the main west-wind axis from coast to coast (Fig. 4B). In the Atlantic sector the eastward spread of warm surface temperatures from the eastern seaboard continued, and a less dramatic but more extensive surface warming took place farther south beneath the expanded subtropical ridge. Tropical storm activity was exceptionally weak in both Pacific and Atlantic sectors.

The fast zonal westerly circulation generally continued into fall, disrupted somewhat by a recurrent blocking tendency over eastern Canada and the western Atlantic (Fig. 5A). As a result, the patterns of air temperature anomaly over the American continent and sea temperature anomaly over both oceans changed relatively little from summer to fall (Fig. 4B, 5B). The summer warming of the Bering Sea under the polar anticyclone was, however, extended southward in fall to the northernmost North Pacific as an isolated remnant of this ridge settled over the Aleutians. This, in turn, brought a narrowing of the cold water belt at midlatitudes and together with

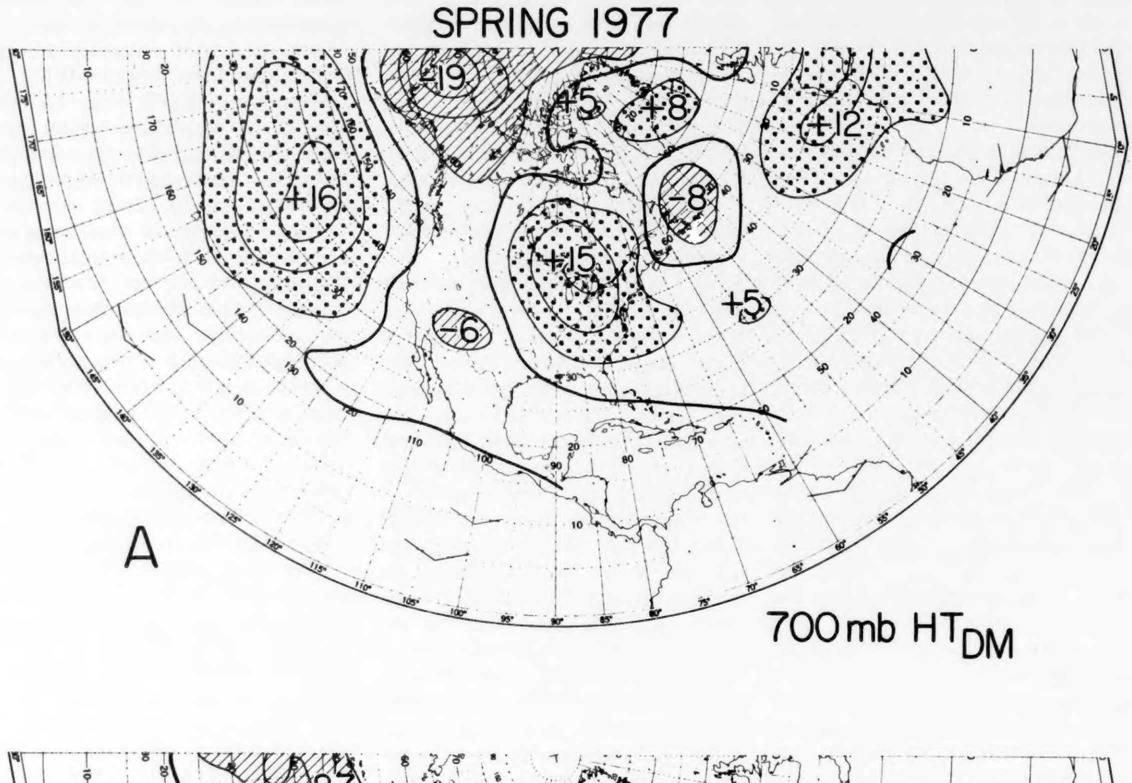


Figure 3.—Mean distributions of (A) 700 mb height anomaly (feet ÷ 10) and (B) sea surface temperature anomaly (°F) for spring 1977.

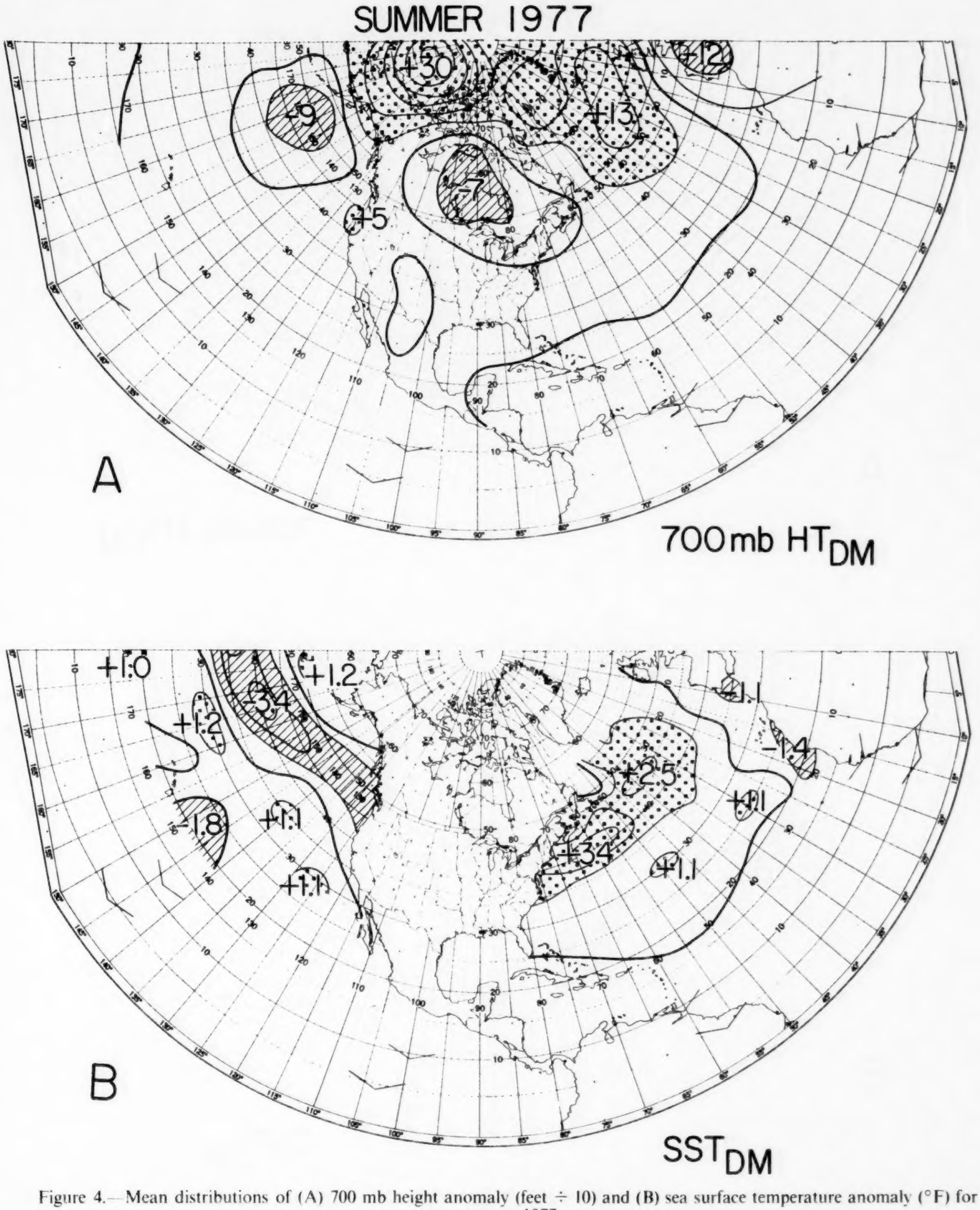


Figure 4.—Mean distributions of (A) 700 mb height anomaly (feet ÷ 10) and (B) sea surface temperature anomaly (°F) for summer 1977.

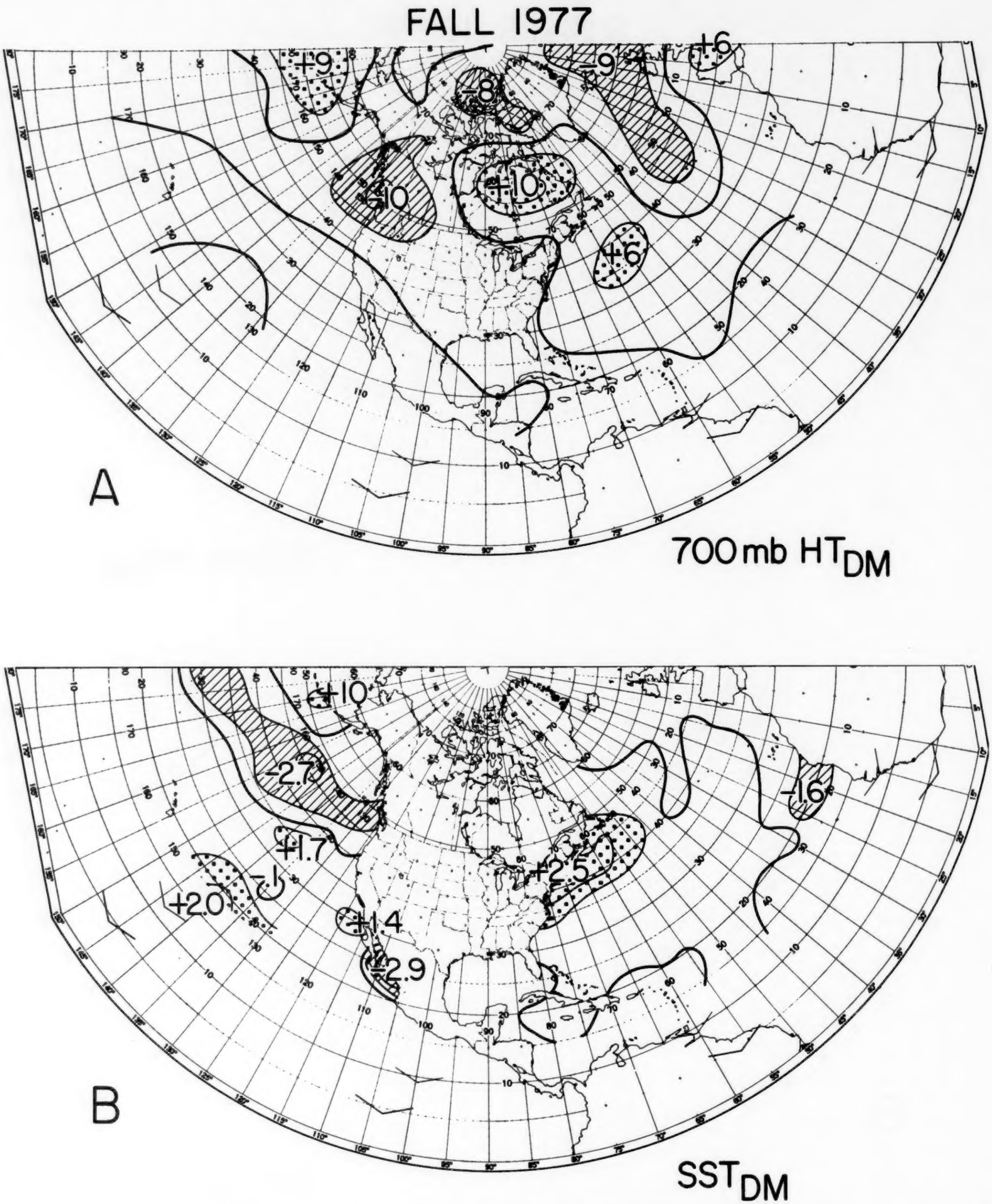


Figure 5.—Mean distribution of (A) 700 mb height anomaly (feet ÷ 10) and (B) sea surface temperature anomaly (°F) for fall 1977.

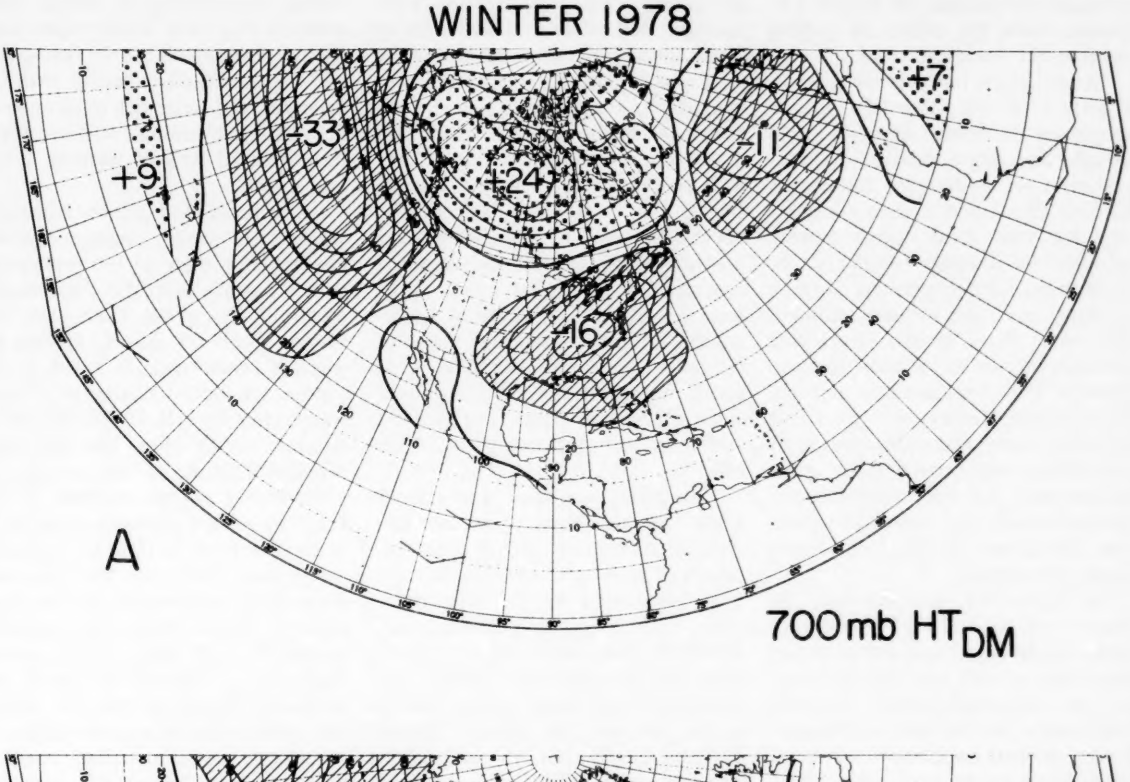


Figure. 6—Mean distributions of (A) 700 mb height anomaly (feet ÷ 10) and (B) sea surface temperature anomaly (°F) for winter 1977-78.

enhanced storminess off British Columbia, drew the center of cooling closer to the American coast.

These changes, however, were largely a feature of the early fall. As fall progressed the normal retrogression of troughs and ridges initiated the establishment of a different but rather familiar circulation anomaly pattern with the west coast trough moving offshore to intensify south of the Aleutians, with a distinct ridging tendency over the western seaboard and with a lee trough developing downstream in a variable location between the Appalachians and the Mississippi Valley. As yet these features were relatively weak or intermittent and, occurring late in the season, were not even evident in the seasonal mean, but they were significant precursors of the forthcoming winter circulation.

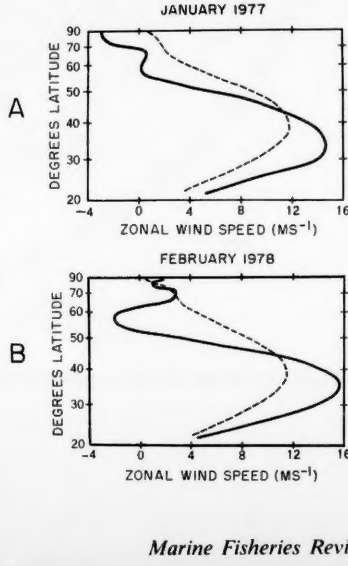
As Figure 6A demonstrates, the winter circulation of 1977-78 was once again characterized by a well amplified wave train at mid- and high latitudes, and its component pressure anomaly cells—while less extreme—did display certain marked similarities to those of the previous winter. Once again, a deep full-ocean trough (-330 feet) centered south of the Aleutians brought widespread cooling to the surface waters of the northern North Pacific (Fig. 6B). Once again (Fig. 1A, 6A), a zonal belt of negative height anomaly extended between deep troughs over eastern North America and the eastern Atlantic; and, once again, an intense polar ridge over west and central Canada helped displace these midlatitude troughs and the main west wind axis far to the south of normal, aided by the SST anomaly pattern in the central and eastern Pacific which was compatible with major storminess. However, the two winter circulation patterns did display important differences also which were particularly significant over west and southwest America. Although a full-latitude west coast ridge was able to form on limited occasions throughout the winter, the near record cold in the midwest and eastern states was not due to this cause but to severe Arctic outbreaks from the high pressure center over Canada. The displaced Pacific westerlies were stronger this winter and were able to break through the southern half of the west coast ridge. The eastward extension of the Pacific trough over California (as in the seasonal mean, Fig. 6A) brought frequent storm activity and twice-normal precipitation to break the 2-year drought in the southwest, aided by a moisture-laden southerly flow around the southern remnant of the west coast ridge (centered over Baja California). Locally, this southerly flow and the anticyclonic conditions over Baja California were also able to bring about some renewal of ocean warming off southern California and Mexico (Fig. 6B).

Continuing on their low-latitude track, the disturbances in the subtropical westerlies picked up additional moisture crossing the Gulf of Mexico and, invigorated by the sharp baroclinic contrast at the Atlantic coast, continued eastwards along a southerly path towards southwest Europe. This excess of kinetic energy above normal at low latitudes, the deficit at higher latitudes between lat. 45° and 60°N, and the similarity (in this regard) between the two winters under discussion is well illustrated by Figures 7A and 7B (from Wagner, 1977, and Dickson, 1978, respectively) which compare the extreme conditions of January 1977 with those of February 1978. There is little evidence of this vigorous southerly storm track in the SST anomaly distribution for the North Atlantic (Fig. 6B); it is perhaps reflected in the new cooling center west of Spain, but in the western Atlantic the warmth along the Atlantic seaboard showed little change from the fall.

Finally, Figures 8 and 9 summarize the anomalous tendencies of atmosphere and ocean for the year 1977 as a whole. As expected (Fig. 8) the mean annual distribution of 700 mb height anomaly is mainly a reflection of the extreme developments of the winter season, with its polar ridge, Pacific trough, pan-Atlantic trough, and subtropical ridge anomalies all clearly displayed. The influence of the winter season is also evident in the mean annual distribution of Pacific SST anomaly (Fig. 9A). Colder water than normal occupies all but the Bering Sea and the southeastern Pacific, with the principal cold water belt (core anomalies -2.4°F) extending zonally beneath the displayed axis of westerly winds and storms.

The general cooling at the American seaboard in spring, summer, and fall has left little trace of the preexisting winter warmth beyond a slight northward inflexion of the 0° isopleth, but further south off Baja California an isopleth center remains which is the product of local warming in all four seasons (see Fig. 1B, 3B, 4B, 5B). In the Atlantic sector (Fig. 9B) the only marked feature is the tongue of abnormally warm surface water (+3.2°F) which persisted with little change off the Atlantic seaboard throughout 1977. In this location, where SST gradients are at their most extreme, there is always the possibility of error through uneven distribution of sampling, and certainly there are occasions throughout the year where this persistence of warmth seems at variance with the prevailing sense of the circulation. Nevertheless the very

Figure 7.—Mean 700 mb zonal wind speed profiles for the western half of the Northern Hemisphere for (A) January 1977 and (B) February 1978. Solid lines show the observed profiles, dashed lines show the normal. (From Wagner, 1977, and Dickson, 1978, respectively.)



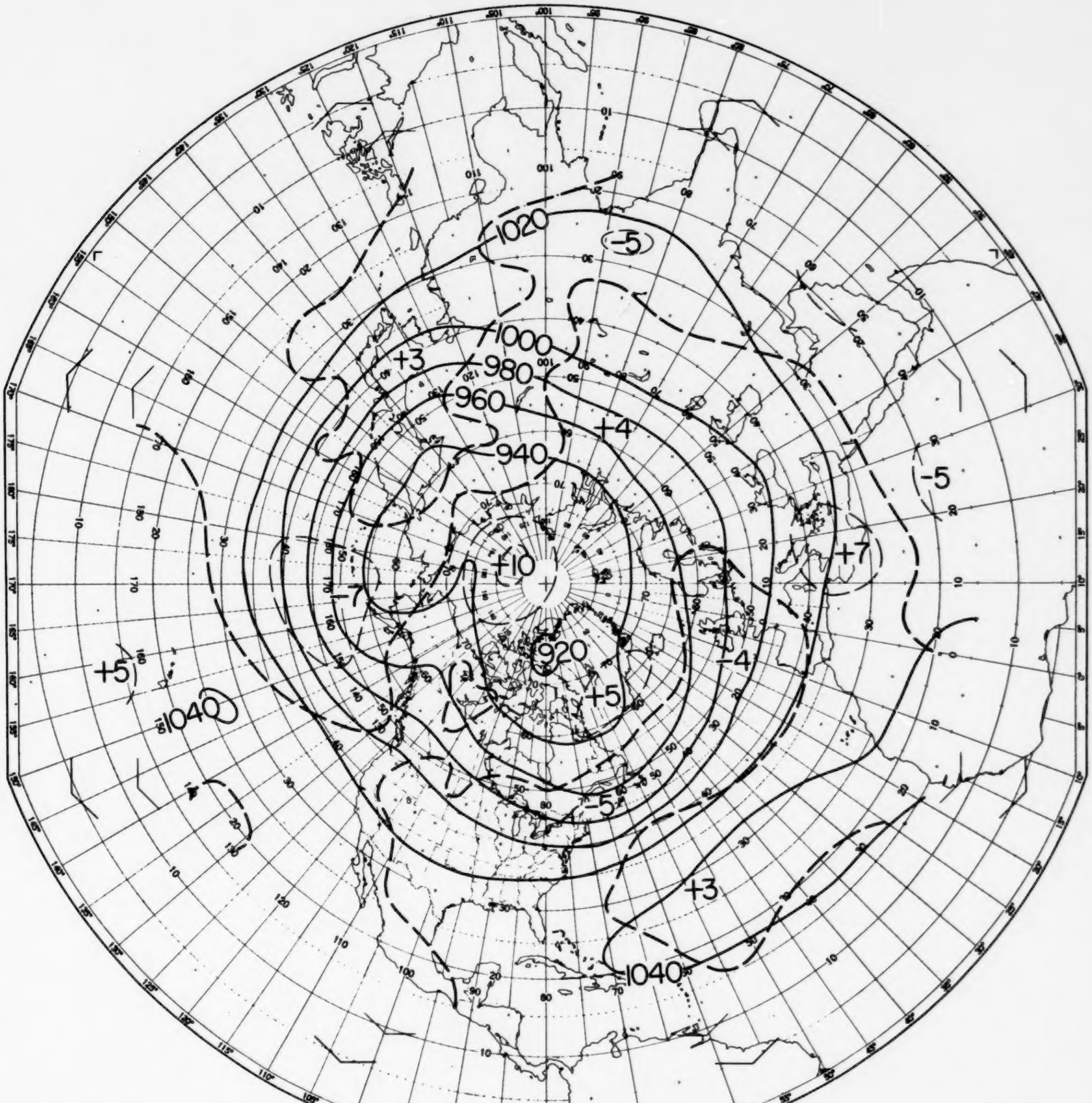


Figure 8.—Mean annual distribution of 700 mb height and its anomaly (feet ÷ 10) for 1977.

extent and persistence of the warming does suggest that the data are meaningful, and if so a possible explanation might concern the record Gulf Stream transport following the frigid Arctic outbreaks of the winter season.

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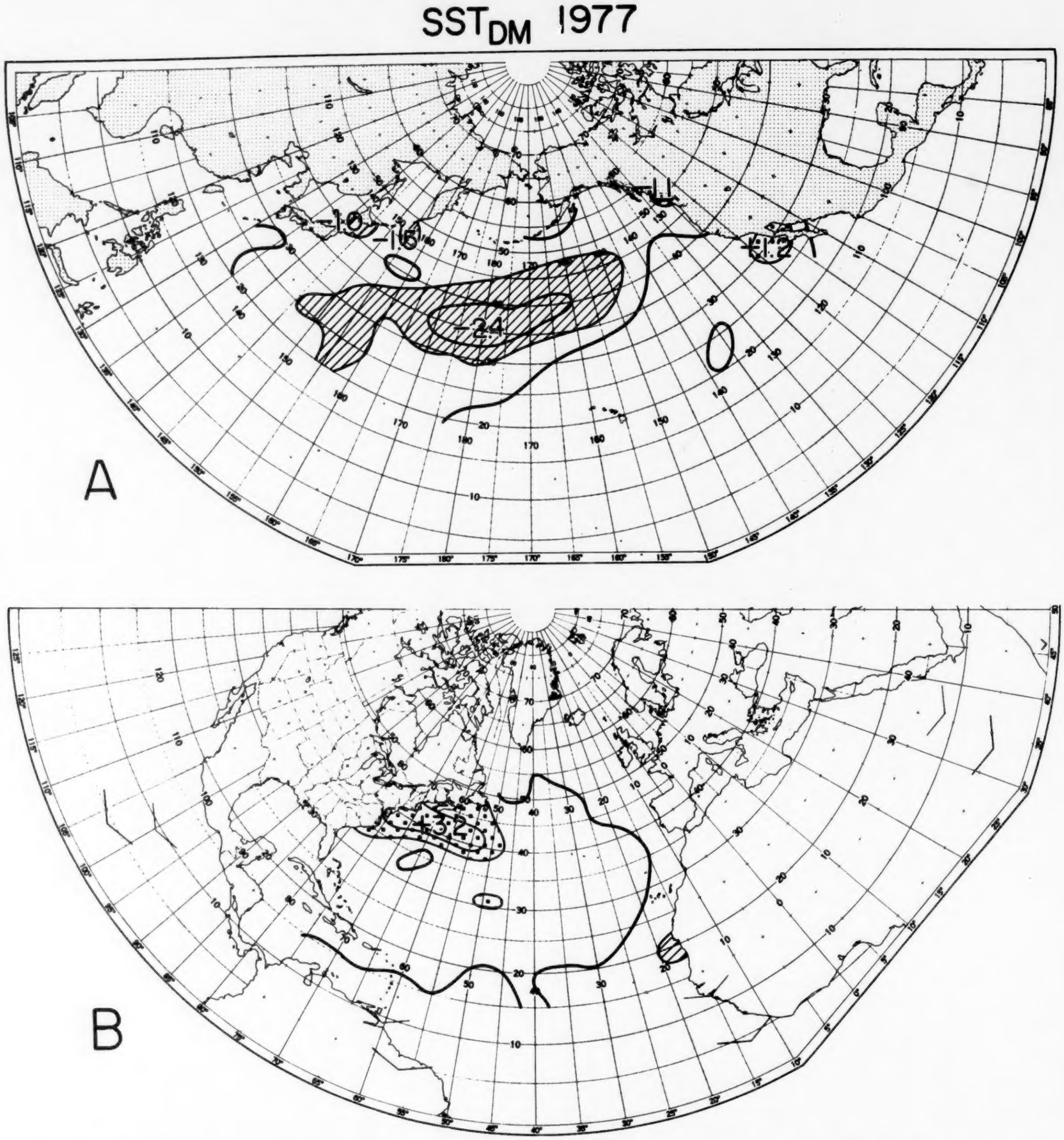

Figure 9.—Mean annual distribution of sea surface temperature anomaly (°F) in 1977 over the Pacific and Atlantic sectors.

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Marine Environmental Conditions off the Coasts of the United States, January 1977-March 1978

Foreword

"Scientific studies of the fisheries are scarcely 100 years old, although fishing itself is an ancient occupation. The birth of fishery science can be attributed in large degree to the great fluctuations in abundance that characterize almost all fishery resources. The causes of these fluctuations are still imperfectly known, but it is important to understand the separate effects of man and nature and the interactions between them in determining abundance of living resources, so that one will not be confused with the other. The wrong remedial measures might not only fail to have the desired effect, but also place unnecessary restrictions on the fisheries at a time of economic hardship. Much of the effort of fishery scientists has been devoted to understanding the effects of these two major sources of variation." (McHugh, J. L. 1976. Effects of climatic change on fisheries. *In* Hearings before the Subcommittee on the Environment and Atmosphere of the Committee on Science and Technology in regard to the National Climate Program Act, U.S. House of Representatives, 94th Congress, 2nd Session, 18-27 May 1976, p. 544-562.)

"After many decades of intensive research in various parts of the world, it is now accepted that natural fluctuations in the size of fish stocks are of common occurrence and also that individual year classes of important food-fishes may vary widely in their numerical strength. The explanation of these fluctuations is one of the most important problems confronting fishery science, for it provides the key to intelligent prediction of the future supply of fish and can, in certain cases, be useful in schemes to control or modify survival. Yet it is noteworthy that, particularly in marine investigations, understanding of the casual factors in population fluctuations has been slow in developing.

"A number of serious difficulties confront investigations of this kind. Wholly satisfactory means may not be available to obtain an accurate quantitative expression of the changes in strengths of year classes. The main obstacle, however, seems to lie in the difficulty of obtaining an accurate description of the environmental events which transpire during that period in the life history when the strength of a year class is determined. Even if it is possible to relate these events to the changes in survival, there remains the task of establishing with reasonable certainty that the observed relationships are direct and not merely associated with some still unidentified factor or factors. Thus, it is not surprising, in view of the complexity of the marine environment and the various impediments to precise analysis, that ventures into this field generally have not been successful." (Ketchen, K. S. 1956. Factors influencing the survival of lemon sole (*Parophrys vetulus*) in Hecate Strait, British Columbia. J. Fish. Res. Board Can. 13:647-694.)

Marine Environmental Conditions off the Coasts of the United States, January 1977-March 1978—Introduction

ROBERT A. PEDRICK

Fishermen have long recognized that changes in the marine environment can have pronounced short-term effects on the distribution and abundance of fish. Even the novice weekend angler knows that the chances of catching fish can be drastically affected by weather and weather-induced changes within the sea. Commercial and experienced recreational fishermen learn to "read the weather" and are guided by weather and sea conditions in their fishing activities.

The longer term, larger scale changes in oceanic environmental conditions, commonly referred to as climate, can have even more lasting effects on the state of marine fisheries resources. Just as cycles of drought and flood or heat and cold can limit terrestrial crop yields, so cycles of suitable and unsuitable ocean currents, temperatures, etc., can limit marine populations. Superimposed on naturally occurring environmental fluctuations are those changes attributable to man, such as fish harvesting and pollution. Failures of fisheries such as Japanese sardine, California sardine, Hokkaido herring, Norwegian herring, and Pacific mackerel are largely attributed to a combination of heavy fishing and long-term changes in environmental conditions.

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At times the changes in the oceanic environment can have devastating effects. For example, "El Niño" conditions (a shift in wind-driven currents that results in diminished upwelling of nutrient-laden productive water) off the coast of western South America during 1972 was associated with the collapse of the Peruvian anchoveta fishery.

On the other hand, locating ocean areas with optimal oceanographic conditions for particular species can serve as a valuable tool in the fishermen's search for productive fishing areas. This is particularly true of the highly mobile oceanic species such as tuna. For example, albacore, in their eastward migration in the spring of the year from the central North Pacific and later during the summer in the near-shore waters off the coast of California, tend to associate themselves with the fronts between different water masses which have sharp horizontal gradients of temperature and salinity (Laurs and Lynn, 1977). At such frontal locations the dynamic processes which produce and maintain the gradients also enrich the waters, rendering them more productive from a biological viewpoint (McGary and Stroup, 1956). There the prevailing conditions tend to provide in abundance the food that is sought by predator species.

Because tuna fishermen recognize the usefulness of timely sea surface temperature charts as well as other environmental information in their search for optimal fishing areas, the Southwest Fisheries Center of the National Marine Fisheries Service regularly provides such information in several forms. These include *Fishing Information*, a monthly publication with a biweekly supplement containing environmental charts and narrative information; the Cooperative Tropical Tuna Advisory Programme, which broadcasts environmental charts by radio facsimile (FAX) to fishing vessels; and the Albacore Advisory Program, which provides weekly sea surface temperature charts and narrative texts of fishery conditions to albacore fishermen.

A number of species off the U.S. coast, including shrimp, menhaden, and others, spawn offshore and require onshore surface currents to transport the eggs and larvae into estuarine nursery areas. When onshore currents occur at the appropriate time to facilitate such transport, a good menhaden year class may be expected (Nelson et al., 1977).

As early as 1899, when the Council for the Exploration of the Sea met in Christiania (now Oslo), Norway, to consider North Sea fisheries problems, they recognized the importance of environmental research in seeking their solution. The Council's concern at the time was the failure of a number of North Sea fisheries due to a vast increase in fisheries harvests which had resulted from the introduction of the steam trawler and the otter trawl, and associated over-exploitation of the fisheries. Their approach to the problem was to support two lines of research: One on the problem of over-exploitation of the stocks, and the other on the effects of the environment on the variability of the stocks. These early deliberations resulted in the establishment of the International Council for the Exploration of the Sea and served as the forerunner of numerous international bodies and agreements designed to conserve oceanic fisheries resources.

In recent years many nations have begun unilaterally to manage the fishery resources off their coasts. The United States, for example, by imple-

menting its Fishery Conservation and Management Act (FCMA) in March of 1977, now regulates domestic and foreign fishing within a 200-mile wide fishery conservation zone adjacent to its shores. Since the implementation of FCMA there has been a vastly increased awareness and concern regarding the scientific basis for projecting annual fisheries yields and hence the quotas that can be assigned to domestic and foreign fishermen.

Generally, environmental effects are not included in such yield determinations. This, in large part, is due to the lack of sufficient information on the impacts of changing oceanic environmental conditions on specific resource species. Yield estimates upon which fisheries management strategies are based have traditionally been developed for single species assuming a stable environment or one described by the long-term average of environmental conditions.

Thus yield estimates and derived quotas do not yet adequately reflect the effects of environmental variation, either short or long term. Nor has it yet been possible to include adequately intraspecies or food web interactions, although research is presently underway to develop comprehensive ecosystem models which consider such factors (Laevastu and Favorite [1,2]).

Though the importance of including environmental inputs in yield determinations is recognized by many fisheries scientists, the task of amassing sufficient information to understand such effects is not a simple one. Nor can it be resolved exclusively by workers in any one scientific discipline. Instead, it will require the labors of many specialists, including fishery biologists, oceanographers, meteorologists, and others.

This scene, in general, indicates the complex interaction with entrainment by the California current off the Pacific coast, with the upwelled waters. This upwelling is driven by the alongshore winds from the north during the summer months and the regime is a classic manifestation of offshore Ekman transport. This image was received from the Very High Resolution Radiometer (VHRR) aboard the NOAA-5 satellite during the 1977 upwelling season. Cloud cover is minimal and self-evident. The approximate range of sea-surface temperature here ranges from about 11°C near the central California coast to perhaps 20°C at the southern end. NOAA photograph.

The problems involved in providing quantitative environmental inputs in fisheries yield determinations are numerous and difficult, but they appear resolvable using present technologies. Perhaps the greatest need is that of greater understanding of those oceanic and atmospheric processes, both short and long term, that control the environments of commercial resource species and the productivity of such environments. Though development and testing of fisheries yield models has begun, future models will require much greater understanding and more refined data. Thus, it will be necessary to evaluate research efforts

[1]Laevastu, T., and F. Favorite. 1978. Numerical evaluation of marine ecosystems. Part 1. Deterministic bulk biomass model. Processed Rep., 22 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

[2]Laevastu, T., and F. Favorite. 1978. Numerical evaluation of marine ecosystems. Part 2. Numerical marine ecosystem model (DYNUMES III) for evaluation of fishery resources. Processed Rep. 29 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

and the plans for future data acquisition in terms of anticipated model requirements.

This report is intended to furnish to fishermen and fishery scientists some of the needed information concerning marine environmental variations in 1977 and early 1978, citing the anomalous conditions which may have impacted on stocks of marine organisms. Earlier reports were prepared for 1974 (Goulet, 1976), 1975 (Goulet and Haynes, 1978), and 1976 (Goulet and Haynes, In press). The present report deals with naturally occurring environmental fluctuations without attempting to discuss effects of man's activities, and is not intended as a detailed study of oceanographic processes. Instead it provides an overview of the large-scale oceanic environmental events during the period and describes environmental variations which may affect fisheries yields. Our goal is to provide this type of summary annually, both to fishing interests and to others concerned with the possible impacts of environmental factors on marine living resources off the coasts of the United States.

Since environmental changes can affect fish populations over a broad range of spatial and temporal scales (ranging from days to decades and from meters to hundreds of kilometers), this report cannot cover events occurring in all time and space scales of possible interest. For example, on the Pacific coast, environmental events have been described on monthly or seasonal time scales first on large oceanic scales--and then on smaller, regional space scales by coastal areas proceeding southward, with conditions in Canadian waters off British Columbia included for continuity. The Atlantic coast is similarly discussed from north to south, continuing into the Gulf of Mexico.

For timely monitoring of marine environmental conditions with the necessary continuity in time and space, the primary data available are sea surface temperature (SST), wind, and pressure observations made routinely by ships and transmitted ashore by radio. These observations are numerous along major shipping lanes, but offer poor coverage in other areas where ship traffic is scarce. Various oceanographic analyses are made with data from these and other sources (see Appendix 1 in McLain et al., 1979) including satellite observations. Other measurements of ocean parameters are made nonroutinely by research vessels. These observations and data summaries are provided in various periodicals (see Appendix 2 in McLain et al., 1979).

Only in a few instances do the oceanographers who contributed to this report know enough about the nature of the interactions between environment and the living resources of the sea to enable predictions of the variance in year class strength due to environmental influences. Perhaps the information provided here will stimulate exploration by fishermen and scientists on the effects of environmental interactions on the abundance or distribution of resource species. The contributors to this report welcome comments on any bioenvironmental interactions or other aspects of environment-fisheries interactions that readers of this report may wish to suggest.

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Marine Environmental Conditions off the Atlantic and Gulf Coasts of the United States, January 1977-March 1978

MERTON C. INGHAM

Introduction

The predominant atmospheric events influencing the coastal marine environment in 1977 and early 1978 were two severe winters which yielded record or near-record low temperatures along most of the Atlantic and Gulf coasts. The impact of two successive severe winters on fish stocks on nearshore estuarine waters may have been very significant for some species. Reports have been received of high mortalities in both years of juvenile croaker in Chesapeake Bay and white shrimp in South Carolina's coastal waters.

An unusually large number of warm-core Gulf Stream eddies passed through the Slope Water adjacent to the continental shelf in the Georges Bank and Middle Atlantic Bight areas in 1977. These eddies had direct impact on the lobster and crab fisheries on the outer continental shelf and slope in the form of gear losses due to the strong currents associated with them. Also there were reports of poor catches in the vicinity of the eddies. In addition it is likely that the eddies increased the exchange of Shelf Water and Slope Water and their indigenous biota, which may have led to losses of planktonic larvae of various important species which spawn in the Shelf Water mass.

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Major offshore excursions of the Shelf Water front, up to 80-100 nautical miles (n.mi.) (150-185 km) from its normal position near the shelf edge, occurred in February and March 1978, during a period when there was an unusual absence of warm-core Gulf Stream eddies. This excursion apparently influenced the distribution of Atlantic mackerel off Virginia leading to their passage about 20-30 n.mi. (35-55 km) farther offshore than normal, and consequently their escaping the domestic fishing fleet in that area. There have been no other reports of changes in the distribution of migrating pelagic species in the Middle Atlantic Bight this spring, but the likelihood exists.

The winter of 1976-77 produced unusually strong, persistent northwesterly winds in the Georges Bank and Middle Atlantic Bight areas in January and February. Such winds would produce strong southwestward Ekman transports in the upper layer of the sea. In the area off the North Carolina coast, relatively strong westward components of Ekman transport occurred in January 1977 and February 1978, during the offshore spawning period of Atlantic menhaden. Thus, during those 2 months at least, the larval transports toward the nursery grounds in the estuaries should have been adequate for good survival rates.

Conditions in the New York Bight in the spring of 1977 were not appropriate for a repeat of the development of anoxia in the bottom water off New Jersey which occurred in 1976. Only a narrow band of low-oxygen bottom water developed along about 30 n. mi. (55 km) of the central New Jersey coast, and significant fish mortalities do not appear to have resulted.

The bottom water over the continental shelf in the Middle Atlantic Bight was about 3 to 4°C colder than normal in January and February 1977. By May off southern New England and late June off New Jersey, the temperatures had increased to normal values. It is not known how this 5- or 6-month period of anomalously low temperatures influenced the distribution of demersal species. In January-March of 1978 the bottom water in these areas seemed to be about 2 to 3°C cooler than normal and about 1°C warmer than the previous year.

The cold winter of 1976-77 did not significantly lower the temperature of the water over Georges Bank, but the salinity of this water mass was considerably (up to 1‰) higher. This condition apparently was the result of wind-driven transport of higher salinity water from the Gulf of Maine, where it had developed as the result of invasion of the basins in the Gulf by oceanic water in 1976.

The variation of the Eastern Gulf of Mexico Loop Current apparently did not follow the "normal" pattern at all in 1977 and early 1978. Maximum northward intrusion of the current occurred in February 1977 and January 1978, not during the spring and summer months as assumed by the "normal" pattern. The minimum intrusion occurred in the summer and fall of 1977 and continued into the winter period.

Atmospheric Variations Circulation and Air Temperature

A portrayal of weather conditions during 1977 and the first quarter of 1978 compiled by Haynes[1] from meteorological journals reveals that

[1]Haynes, E. D. 1978. Atmospheric circulation in 1977. Unpubl. rep., 7 p. Resource Assessment Division, Office of Science and Environment, National Marine Fisheries Service, NOAA, Wash., DC 20235.

the first 2 months of the period saw a continuation of the severe winter conditions extant along the Atlantic and Gulf coasts in late 1976. Strong, persistent westerly flow over the North Pacific and anomalously cold surface water temperatures in that ocean established the atmospheric circulation pattern which produced the bitter winter of 1976-77 in the eastern United States. The circulation led to the advection of unusually cold and dry continental polar air southeastward across the midwest and Atlantic seaboard.

The effects of this invasion of cold air on coastal weather are evident in the average monthly air temperature anomaly records from coastal weather stations from Portland, Maine, to Brownsville, Tex. (Fig. 1, 2 and Table 1). Significant negative anomalies from long-term averages ranging from -5.3° to -13.0°F, were reported at all stations in January 1977. The strongest anomalies were in the Middle Atlantic Bight, from New York to Norfolk, but those in the South Atlantic Bight and Gulf of Mexico were only a few degrees warmer. In February the severe cold weather moderated considerably, especially in the Middle Atlantic Bight where the strongest anomaly was only -1.1°F at Atlantic City. In the South Atlantic Bight and Florida coastal stations the anomalies were still relatively strong, with Jacksonville showing a value of -6.3°F.

About the end of February a strong atmospheric ridge replaced the wintertime trough over the eastern states, bringing unusually warm temperatures for the early spring. This condition was very apparent in the coastal air temperature anomalies for March (Table 1), with positive anomalies up to 6.6°F showing for all stations except for Corpus Christi, which still showed a weak negative anomaly.

By summer the ridge had moved offshore and nearly normal conditions prevailed, but air temperatures remained above the long-term means by as much as 4.5°F (September in Norfolk and Corpus Christi), with the most extensive and persistent positive anomalies occurring in the Middle and South Atlantic Bights.

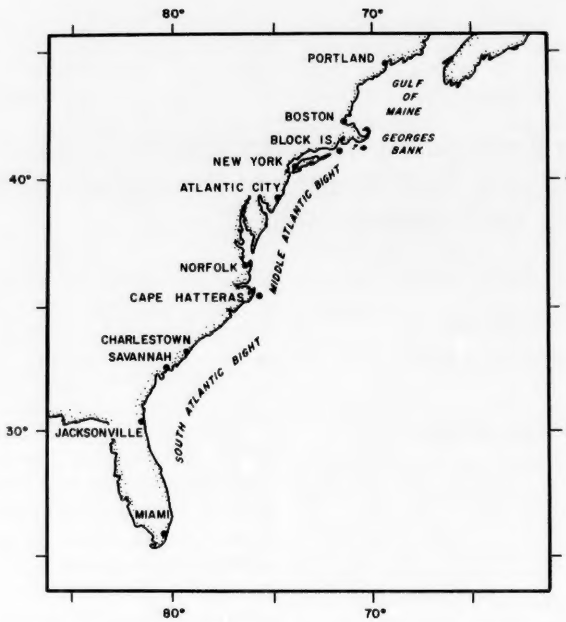


Figure 1.—Atlantic coastal area and weather stations from which data were obtained.

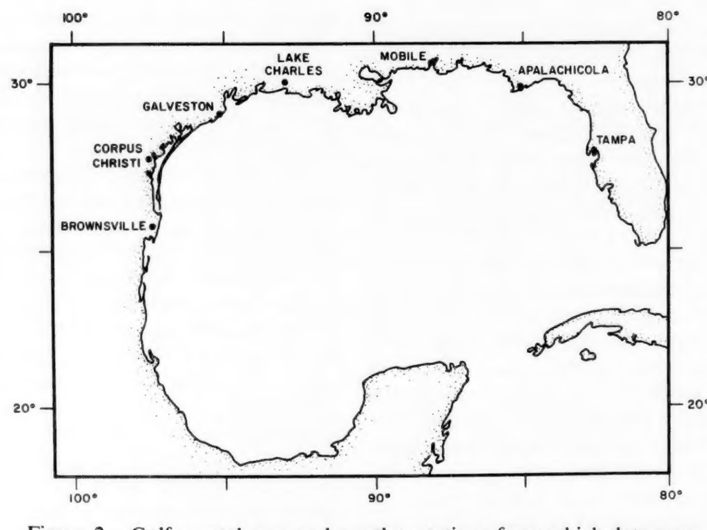


Figure 2.—Gulf coastal area and weather stations from which data were obtained.

Winter circulation patterns returned in October, with upper air patterns very similar to October 1976, except that the ridging in the western United

Table 1. Monthly air temperature anomalies (°F) from selected weather stations along the Atlantic and Gulf coasts. Dark shading indicates negative anomalies of -2°F or larger, light shading +2°F or larger.

	J 1977	F 1977	M 1977	A 1977	M 1977	J 1977	J 1977	A 1977	S 1977	O 1977	N 1977	D 1977	J 1978	F 1978	M 1978
Portland, ME	[illegible]	-1.0	+4.4	-0.3	+1.7	[illegible]	+0.2	+0.2	-1.1	-1.0	+0.8	-0.3	-0.4	-7.7	-1.6
Boston, MA	[illegible]	+0.3	+6.6	+2.7	+4.0	-0.6	+1.6	+2.1	-0.1	-0.1	+2.9	+1.2	-0.7	[illegible]	-1.9
Block Island, RI	[illegible]	[illegible]	+3.2	+1.1	+2.2	+0.4	+1.6	+1.7	+0.3	-0.2	+1.9	+0.6	[illegible]	-4.9	-2.7
New York, NY	[illegible]	-0.1	+4.4	+1.1	+1.9	[illegible]	0.0	-0.3	-0.2	[illegible]	+0.7	-0.6	-2.2	[illegible]	-0.6
Atlantic City, NJ	[illegible]	-1.1	+4.7	+0.8	+0.1	[illegible]	+0.2	+1.9	+2.4	-1.8	+3.6	+0.3	-2.3	-10.1	-1.6
Norfolk, VA	[illegible]	+0.1	+6.6	+4.1	+1.5	-0.2	+3.1	+4.1	+4.5	-1.2	+3.2	+1.2	-3.5	[illegible]	[illegible]
Cape Hatteras, NC	[illegible]	-1.5	+4.6	+4.0	+2.6	+0.3	+2.8	+2.0	+3.6	-1.8	+3.4	+1.1	-3.3	-10.1	-0.5
Charleston, SC	[illegible]	[illegible]	+4.1	+1.8	+0.7	+3.3	+3.6	+1.8	+3.5	[illegible]	+5.0	+0.7	-5.1	[illegible]	-1.3
Savannah, GA	[illegible]	[illegible]	+4.1	+1.5	+0.7	+2.9	+2.2	+0.5	+2.7	-3.0	+4.1	-0.4	-6.0	[illegible]	-1.7
Jacksonville, FL	[illegible]	[illegible]	+3.8	-1.0	-1.3	+2.1	+1.7	+0.9	+1.9	[illegible]	+1.3	[illegible]	-6.0	-8.8	-2.5
Miami, FL	[illegible]	-1.7	+3.6	-0.2	-1.0	+0.7	+1.4	+0.3	+1.3	-1.3	+1.8	+0.8	-3.2	-4.6	-2.4
Tampa FL	[illegible]	[illegible]	+4.9	-0.5	-0.7	+2.7	+1.0	+0.8	+1.5	[illegible]	+0.9	[illegible]	-5.4	-8.6	-1.8
Apalachicola, FL	[illegible]	[illegible]	+2.2	-1.3	-1.8	+1.1	-0.1	-0.8	+1.7	[illegible]	+1.2	-2.0	-8.1	-8.9	-4.4
Mobile, AL	[illegible]	-1.8	+3.2	+0.3	+0.8	+2.6	+1.9	+1.9	+3.4	[illegible]	+2.4	-2.1	-10.0	-8.9	-2.7
Lake Charles, LA	[illegible]	-0.9	+1.8	-0.6	+0.8	+0.6	-0.3	-0.9	+1.6	-1.0	+1.6	-1.0	[illegible]	-9.5	-2.5
Galveston, TX	[illegible]	-1.1	+1.2	+0.8	+0.2	-0.3	-0.5	-0.7	+1.4	-0.3	+1.6	+0.7	-8.6	-9.2	-2.7
Corpus Christi, TX	[illegible]	-1.0	-1.1	-1.3	+0.9	+0.5	-0.2	+1.6	+4.5	+1.8	+2.6	+2.8	-7.1	-7.9	-1.0
Brownsville, TX	[illegible]	-1.5	+1.3	-1.2	+0.9	-0.2	+0.2	+1.5	+2.7	+1.4	+1.7	+1.6	-5.7	-7.5	-0.9

States was not as intense. Consequently, moist maritime air masses were common, producing conditions that were not as cold, but stormier and wetter than the previous fall. Negative anomalies as large as -4.4°F were recorded for October at all stations except Corpus Christi and Brownsville. However, positive anomalies returned in November for all stations as the weather moderated, and the anomalies remained weakly positive in December for most of the stations.

In January and February of 1978, severe cold stormy conditions settled over the eastern two-thirds of the United States, and total snow cover exceeded that of 1977. Unlike the preceding winter, sudden warming did not occur in late February and March. All the coastal weather stations showed negative air temperature anomalies through March.

As pointed out in Anonymous (1978), the two successive cold winters (1976-77 and 1977-78) combined may have set a new record for paired cold winters. The impact of these very cold winters has been greatest in estaurine areas, where water temperatures have fallen to record lows. For example, there was extensive mortality both winters among the juvenile croakers, which overwinter in the tributaries to Chesapeake Bay, yielding two successive short year-classes in this commercial fish stock[2]. Similarly, in South Carolina coastal waters the white shrimp stocks were decimated by record cold temperatures both winters, yielding two successive disastrous trawling seasons (Hamrick, 1978).

River Runoff

Records of streamflow in the Middle Atlantic Bight region reflect the precipitation patterns for 1977 and early 1978. A summary of flow of the streams tributary to Chesapeake Bay prepared from U.S. Geological Survey records by Haynes[3] revealed that the exceptional warming of late February and March of 1977 yielded a record mean flow of 195,000 cubic feet per second in March. Flow records for the Hudson River and cumulative discharge into Long Island Sound show a record value of 43,000 cubic feet per second for the former and a high value of 82,000 cubic feet per second for the latter in March.

In all three river systems, flows remained relatively high in April, then fell to below-average values during May-August. Flows increased dramatically in September and October, leading to record or near-record values during the latter month. The flow levels then remained substantially above average through January 1978, then fell to average or below in February and March in the Long Island Sound tributaries, but the Chesapeake Bay tributaries rebounded in March to record levels.

Wind-Driven Transport

The unusual winter of 1976-77, which was much in evidence in January and February, carried with it substantially anomalous wind conditions which in turn produced unusual wind-driven (Ekman) transports in the upper layer of the water column. Time line portrayals of the monthly average Ekman transport vectors for 1977 and the first quarter of 1978 and for 1964-73 computed from mean monthly atmospheric pressure fields[4] provide a graphical description of these anomalous conditions (Fig. 3, 4) off the Atlantic and Gulf coasts.

Along the Atlantic coast in 1977, the unusually large magnitudes (about twice the 1964-73 average) of the southwestward transports in January and February in the northern area and in January in the central area were a manifestation of the patttern of strong, prevailing northwesterly winds, continuing from the last 2 months of 1976. The southern area experienced transport to the west-southwest instead of

[2]Wojcik, F. J. Effects of cold winter on Virginia's finfish. Press release, 17 April 1978. Virginia Institute of Marine Science, Gloucester Point, VA 20362.

[3]Haynes, E. D. 1978. Freshwater runoff into Chesapeake Bay during 1977. Unpubl. rep., 2 p. Resource Assessment Division, Office of Science and Environment, National Marine Fisheries Service, NOAA, Wash., DC 20235.

[4]Pacific Environmental Group, National Marine Fisheries Service, NOAA, c/o Fleet Numerical Weather Central, Naval Post Graduate School, Monterey, CA 93940.

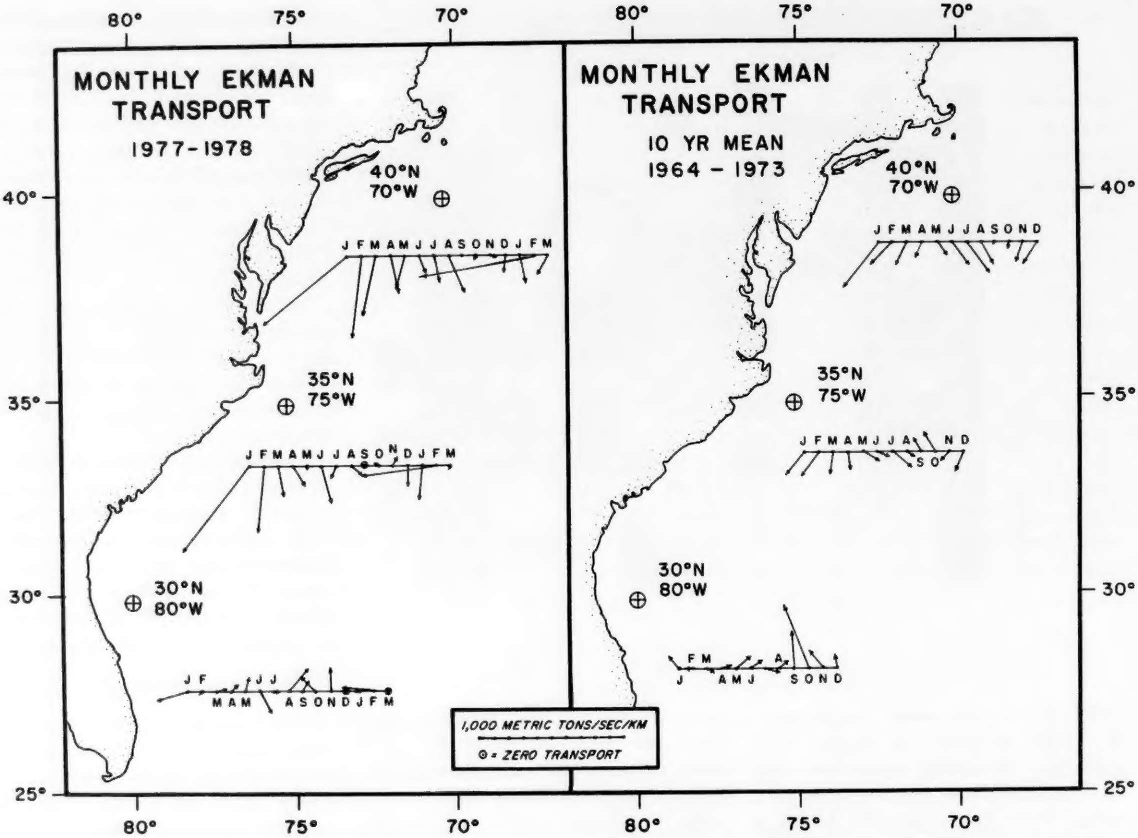


Figure 3.—Average monthly Ekman transports for January 1977-March 1978 and 1964-73 at selected grid points along the Atlantic coast. Data were computed from mean monthly atmospheric pressure fields by the NMFS Pacific Environmental Group, Monterey, Calif.

the usual northwest at about twice the usual magnitude in January, as a consequence of the northwesterly winds produced by the winter pattern of atmospheric circulation.

In 1978 in the northern area, the transports in January and March were close to the average magnitude, but the direction in January was south-southeast instead of southwest. It was in February, however, that very unusual Ekman transport conditions prevailed, to the west-southwest at over triple the average magnitude. This condition apparently was in response to strong, prevailing winds from the north-northwest during that month. The central area experienced similarly anomalous February conditions, with a transport over twice the long-term average for that month, directed toward the west. If menhaden spawning south of Cape Hatteras was in progress during that month, the Ekman transport should have been quite favorable for conveying the larvae toward the Carolina estuaries (Nelson et al., 1977). During March, however, the mean transport fell to nearly zero, a condition which would have provided none of the transport required for good larval survival. In the southern area, the transports were relatively small, as is to be expected from the long-term monthly values, but even here an unusually strong westward transport occurred in February.

In the Gulf of Mexico in 1977, the anomalous winter wind conditions were apparently only in the western portion, where the January Ekman transport vector was about 1½ times the average and toward the northwest instead of the usual north-northeast. This shift in transport would arise from prevailing northeast winds as a by-product of the winter circulation pattern. In 1978 a similar, but less intense, pattern showed and prevailed for 2 months, January and February, instead of just one. In the central and eastern Gulf, the only substantial difference in transport in the first

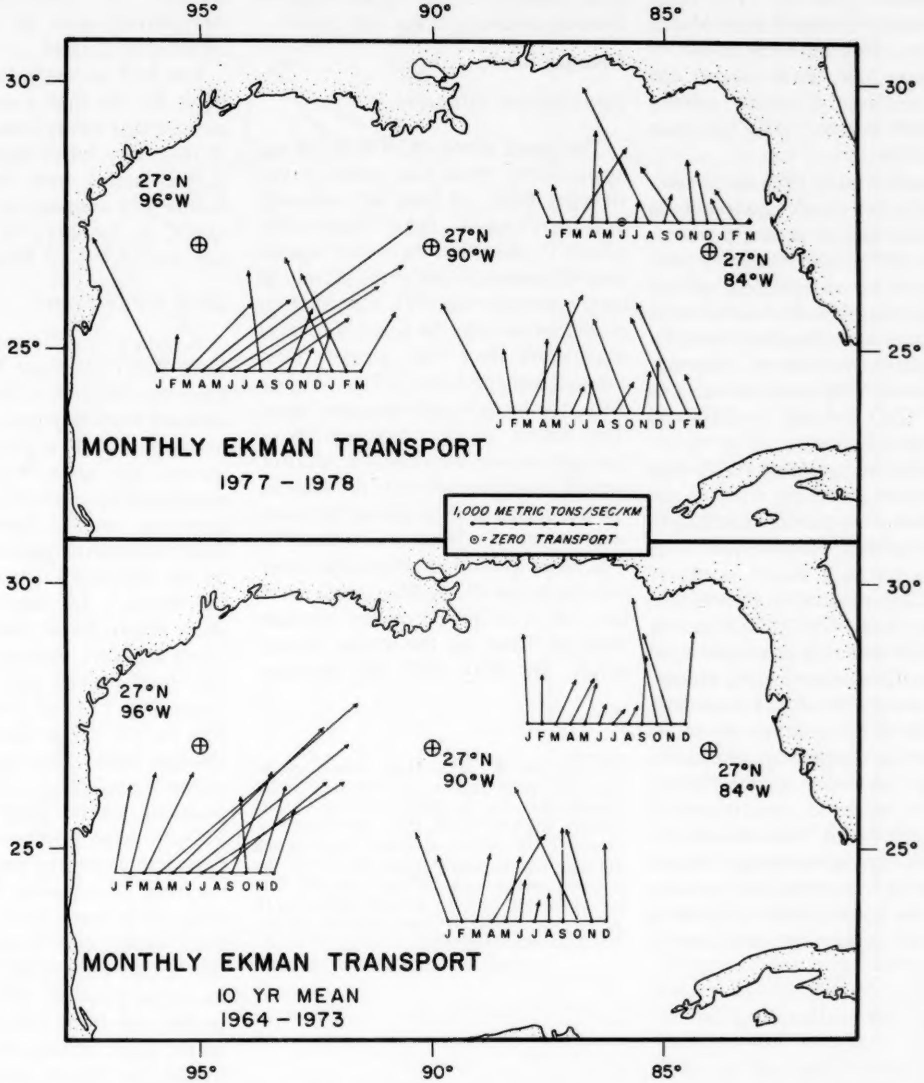


Figure 4.—Average monthly Ekman transports for January 1977-March 1978 and 1964-73 at selected grid points in the Gulf of Mexico. Data were computed from mean monthly atmospheric pressure fields by the NMFS Pacific Environmental Group, Monterey, Calif.

quarter of 1978 was the very small value found in March. This was particularly apparent in the eastern portion.

Oceanographic Variation
Gulf of Maine

Temperature Structure

The strong cooling conditions of the winter of 1976-77 produced slightly (about 1°C) cooler than usual temperatures in the upper waters of the Gulf of Maine. The minimum temperatures measured were found[5] on both the United States and Canadian sides in February when they were less than 1°C. However, the most significant difference between 1977 and the previous year was a decrease in the amount of warm, saline, Slope Water (8°C) intruded into the Gulf at depths of about 150 m and greater. In 1976, 8°C water existed below 150 m in

[5]Pawlowski R. J. 1978. Vertical temperature structure and sea surface salinity in the Gulf of Maine during 1977. Unpubl. rep., 20 p. Northeast Fisheries Center, NMFS, NOAA, Woods Hole, MA 02543.

every transect, but in 1977 these temperatures disappeared from March to October. This reduced inflow of Slope Water may have caused the observed decrease of surface salinity values, from 0.2 to 1.0‰ less than those of 1976.

In January-March 1978 the temperature structure in the surface layers was quite similar to that during the same period in 1977, with the minimum values occurring in February, including values of less than 1°C on both the United States and Canadian sides. At depths greater than 100 m, however, there was very little water as warm as that (<8°C) found early in 1977 and throughout 1976.

Sea surface temperature (SST) data collected from merchant ships in the Gulf of Maine are scarce, especially in the winter months. However, there are some data for each month in the 1° square in the vicinity of Boston (lat. 42°-43°N, long. 79°-71°W) in the monthly SST anomaly charts provided by the Pacific Environmental Group. Not surprisingly, these SST anomalies reflect most of the variation shown by the Boston air temperature anomalies (Table 2), the most outstanding of which are the cold conditions of January 1977 and January-March 1978 and the strong warming of March 1977. During the spring and summer months, the correspondence between sea and air temperature was not as good, because of the big difference in heating processes at sea and ashore.

Georges Bank

Temperature Structure

The severe winter of 1976-77 did not appreciably cool the waters over Georges Bank, at least not eastward and northward from Nantucket Shoals[6,7]. However, there were significant differences found in the salinity of these waters during 1977. The salinities measured early in the year (February) were more than 1‰ greater than average, ranging from 33.5‰ to over 34‰, the highest ever measured there. The source of this high salinity is thought to have been a major influx of oceanic water into the Gulf of Maine in the late spring of 1976, filling the basins with water of about 8°C and 34‰. The water was mixed up into the water column by the strong, cold winds in the late fall of 1976 and driven out over Georges Bank by the strong winter winds. By May 1977 the extreme salinities, in excess of 34‰ had disappeared, and by fall they had returned to normal.

The SST anomaly data for Georges Bank for the first 3 months of 1978 indicate that winter conditions in 1977-78 may have led to significant cooling of the waters over the Bank. The overall SST anomaly for the Bank was -0.8°C in January, -1.4°C in February, and -1.5°C in March.

Shelf Water Front

A surface frontal zone separating the Shelf Water and Slope Water masses is usually located a short distance seaward from the edge of the Bank (200 m isobath). The position of this feature, the Shelf Water front, was monitored by measuring its position as shown in weekly Satellite Observed Gulf Stream Analysis charts produced by the National Environmental Satellite Service[8]. The measurements were made relative to the Shelf edge (200 m) along arbitrary transect lines (Fig. 5). The results along two selected lines, Casco Bay 120 and Nantucket Island 180, for 1977 (Fig. 6) are pertinent to Georges Bank. These results show that along Casco Bay 120 the frontal positions agreed fairly well with the 1973-77 mean positions, except for a period in February and March when the front was observed four times (out of six) to be much nearer the shelf edge than usual, and a period in July-September when it was shoreward of its mean position. During the latter period, the front actually encroached on the Bank, getting as much as 30 km inside the 200-m isobath. Cloudy weather early in 1978 blocked satellite observations along this transect until March when the front appeared to be offshore from its average position for that month, but within one standard deviation of it.

Along the Nantucket Island 180 transect in 1977 the frontal positions

Table 2.—Surface temperature anomalies in the Gulf of Maine area for January 1977-March 1978.

Date	SST anomaly (lat. 42°-43°N, long. 70°-71°W) (°C)	Surface air temperature anomaly (Boston) °F	°C
1977 J	-1.8	-5.9	-3.3
F	-1.2	0.3	0.2
M	2.8	6.6	3.7
A	-08	2.7	1.5
M	-0.6	4.0	2.2
J	-2.3	-0.6	-0.3
J	-1.1	1.6	0.9
A	-0.9	2.1	1.2
S	-0.6	-0.1	-0.1
O	-0.4	-0.1	-0.1
N	0.0	2.9	1.6
D	1.3	1.2	0.7
1978 J	-1.0	-0.7	-0.4
F	-1.5	-3.3	-1.8
M	-1.0	-1.9	-1.1

[6]Wright, W. R. 1978. High salinity in the Georges Bank region in February 1977. Unpubl. rep., 9 p. Northeast Fisheries Center, NMFS, NOAA, Woods Hole, MA 02543.

[7]Davis, C. W. 1978. A summary of spring and autumn bottom-water temperatures on the Atlantic continental shelf from Cape Hatteras to Cape Sable, 1963-77. Unpubl. manuscr., 16 p. Northeast Fisheries Center, NMFS, NOAA, Narragansett, RI 02882.

[8]Gunn, J. T. 1978. Variation in the Shelf Water front position in 1977 from Georges Bank to Cape Romain. Unpubl. rep., 8 p. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882.

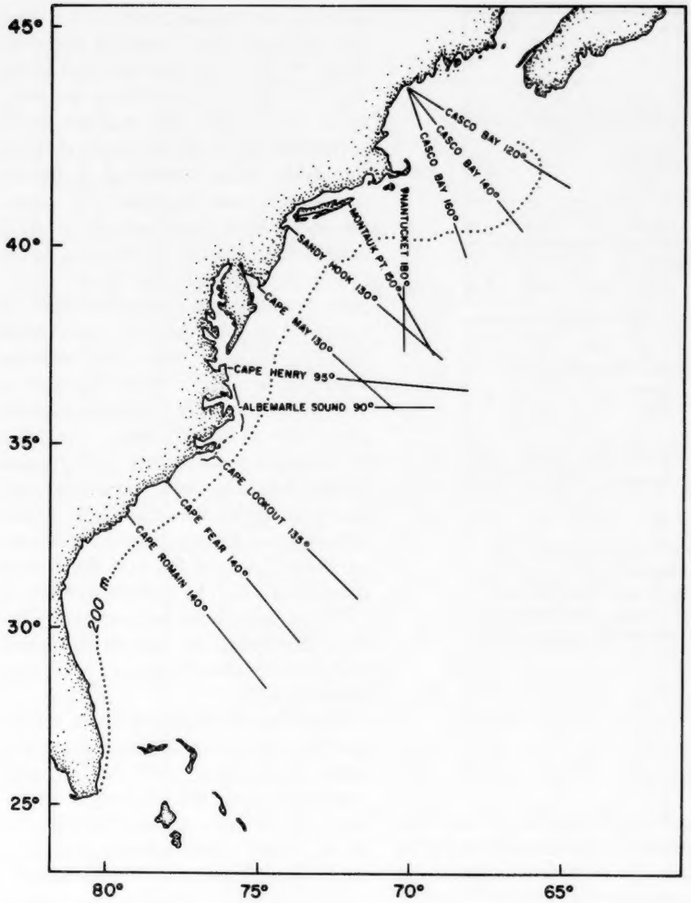


Figure 5.—Location of reference points and bearing lines used to portray the variation of the position of the Shelf Water front relative to the 200-m isobath (dotted line).

were fairly consistent with the mean values except for an offshore excursion in late July and one onshore in November, which was associated with the movement of warm-core Gulf Stream eddies south of Georges Bank. The spring and summer periods, when encroachment usually occurs, did not provide good viewing conditions about half the time, but the good views which were available showed the front to be farther up on the Bank than average, except for the offshore excursion in July mentioned above.

In 1978, the front was observed to be more onshore than normal in January and about average in February, then it moved offshore steadily in March until it was about 150 km offshore in early April. This last position, more than four standard deviations offshore of the mean, is associated with the total disappearance of warm-core eddies in the Slope Water for the first time in about 5 years of satellite monitoring.

Middle Atlantic Bight

Temperature Structure

The variation of sea surface temperature (SST) in the Middle Atlantic Bight in 1977 showed some of the same temporal and spatial patterns shown by the coastal air temperature anomalies. A plot of the SST anomalies for selected 1° squares in Atlantic coastal waters (Fig. 7), produced by the Pacific Environmental Group, shows the most intense negative anomalies occurring in February, about a month after the strongest air temperature anomalies. The lag time is not unexpected because of the greater thermal inertia of the ocean in comparison with the atmosphere. The locations of the strongest negative anomalies of SST are off Virginia, about 150-200 n.mi. south of Atlantic City, N.J., the apparent center of the negative anomaly pattern for the atmosphere. This displacement is also to be expected when one considers the direction of the winter winds and the drift of the Shelf Water mass.

Substantial positive SST anomalies appeared off the New Jersey-Virginia coast during April, once again about a month after the unusual warming in the atmosphere in March. These warm anomalies persisted off the Delmarva Peninsula through July, but occurred sporadically off New Jersey and Virginia.

In 1978, the SST anomaly patterns closely paralleled the anomalously cool air temperatures in January-March. The SST anomalies were about as strong as in 1977 and were centered off Virginia again, but they persisted longer, through March at least.

The unusually cold weather of January and February 1977 left its mark on the Shelf Water mass in the Middle Atlantic Bight. Normally, minimum water temperatures, down to about 3°C nearshore, are reached during February or March, and during this time the water mass is well mixed and vertically isothermal. Stratification and thermocline development normally begins in April or May, sealing off the cold bottom water from above so that it warms only slowly throughout the summer months, until the fall overturn in October or November.

Based on expendable bathythermograph (XBT) data transects across the

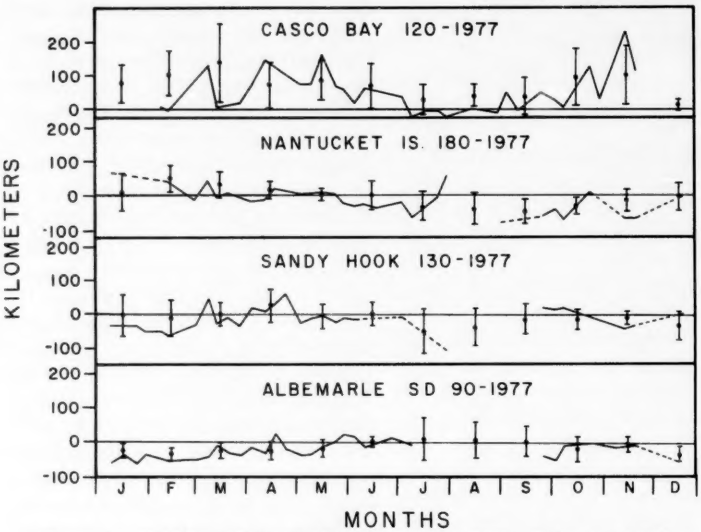


Figure 6.—Positions of the Shelf Water front in 1977 relative to the 200-m isobath (positive distances are seaward) along selected bearing lines. A dashed line segment indicates a 20-30 day gap in the data, and an omitted line segment indicates a gap greater than 30 days. Large dots indicate monthly means for the 1973-77 period and bars indicate a range of ± 1 standard deviation for the same period.

shelf off Sandy Hook, N.J.,[9] the winter minimum temperatures in Shelf Water in February 1977 ranged from less than 0°C nearshore to 9°C at the shelf break 50-90 n.mi. farther offshore. By April, warming and stratification had begun, with the bottom water temperatures ranging from less than 4°C nearshore, still colder than normal, to 9°C at the shelf break. These low temperatures prevailed until early June, but by late in the month warming and mixing had raised the minimum bottom water temperatures to about 7°C, which is normal for that time of year. Gradual warming occurred throughout the summer and early fall until the overturn began in October, when the minimum bottom temperatures had risen to greater than 10°C.

Thus, the only significant temperature anomaly in the bottom water on the shelf in the central portion of the Middle Atlantic Bight in 1977 was the unusually cold temperatures persisting from January to June.

The temperature structure observed off New Jersey in January-March 1978 was less extreme than for the first quarter of 1977. The minimum Shelf Water temperatures, measured in February, ranged from less than 2°C nearshore to greater than 6°C at the shelf break. Surface warming began in late March with the nearshore temperatures climbing to 4°-5°C in response to the warmer air present along the eastern seaboard (Table 1).

A similar cycle of bottom temperatures was reported[10] from XBT data collected on transects across the shelf off southern New England (approx. long. 71°W) at the northern end of the Bight. A portrayal of bottom temperatures on a time VS bottom depth coordinate grid (Fig. 8) shows that the minimum values, measured in February-March, were less than 1°C nearshore, which was about 3°-4°C colder than found in previous years (1974-76). Analysis by Davis (footnote 7) of bottom temperatures from spring (February-March) groundfish surveys showed that the average value off southern New England in 1977 was about 2.5°C colder than the long-term (1968-77) mean. By May the bottom temperature pattern was much like those observed in previous years, so in this area the effects of the unusually severe cooling in the winter of 1976-77 lasted for just the first 4 months of 1977. In the first quarter of 1978 the minimum bottom temperature, measured in March, was less than 2°C nearshore, about 1° warmer than in 1977.

The timing and extent of the winter cold bottom water temperatures on the outer continental shelf are in part dependent upon the passage of warm-core Gulf Stream eddies in the adjacent Slope Water. These eddies, with their anticyclonic (clockwise) circulation, apparently first inject warm, saline Slope Water shoreward then draw off cooler, less saline Shelf Water seaward as they pass. For example, maximum cooling on the outer shelf was recorded in February just after eddy 76D had passed, but was interrupted by the passage of eddy 76G and reestablished in mid-March after the eddy had left the area. By late March, however, seasonal warming became evident.

The cooling and deepening of the surface layer, which marks the end of the annual heating cycle, began off southern New England in September. This was accompanied by warming of the bottom water, as mixing progressed down through the water column. The timing of this bottom temperature rise is variable from year to year, generally occurring during the September-November period. In early November 1977, when the warming of bottom water was approaching its

[9]Cook, S. K. 1978. Water column thermal structure across the shelf and slope southeast of Sandy Hook, N.J. in 1977. Unpubl. rep., 8 p. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882.

[10]Crist, R. W., and J. L. Chamberlin. 1978. Bottom temperatures on the continental shelf and slope south of New England during 1977. Unpubl. rep., 17 p. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882.

	1977												1978			
	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A

Square	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A
1 44N 66W		-1.7 1		-.3 1	0.0 2	1.2 5	1.9 17	2.3 8	0.7 6	1.2 1	2.4 2		1.1 6	-.2 10	0.7 5	0.9 4	
2 43N 68W			0.6 1		0.9 3	1.4 1	-.9 1		-1.3 2	1.6 3	0.0 4	1.1 8	0.8 3	0.4 2	-.7 1	-.2 4	
3 41N 69W		-.2 6	-1.1 16	-.3 22	0.5 23	0.0 15	1.1 6	-.3 10	-.9 13	-.2 19	-1.0 22	-.4 24	0.6 12	-.4 8	-1.9 8	-1.6 20	
4 40N 71W		-1.1 38	-.9 63	-.9 41	-2.2 7	0.4 8	0.6 13	-.4 11	-1.4 15	-.4 16	-1.4 8	0.6 19	-1.1 12	0.4 10	-.7 17	-1.9 22	
5 40N 72W		-1.5 44	-1.8 10	-.6 25	-1.5 5	0.4 5	-.4 11	0.3 10	0.4 7	-1.3 6	-.9 11	-.9 2	-.4 7	1.1 2	-.4 3	-2.7 10	
6 39N 73W		-.3 10	-2.7 7	-.9 13	1.0 16	0.6 4	1.2 15	-.5 11	-.4 16	0.8 26	-2.7 16	0.6 17	-.2 17	-.4 18	-1.1 10	-1.1 14	
7 37N 74W		-.6 40	1.0 34	0.6 57	2.6 35	2.0 50	1.1 32	1.1 28	-.3 36	0.6 52	-1.5 37	-2.4 37	0.9 27	0.7 14	-2.4 30	0.8 47	
8 36N 75W		-2.6 30	-4.0 10	-1.2 19	2.4 7	-1.1 25	-.3 26	1.3 22	-.5 32	1.4 31	-2.0 17	-1.8 18	-1.3 13	-3.6 12	-3.6 28	-2.8 30	
9 34N 75W		-.6 25	-1.4 16	0.6 22	0.4 35	-.7 28	0.2 31	0.8 22	-.8 18	-.2 50	-.3 15	1.1 26	0.0 25	-1.0 23	-.5 26	-1.6 34	
10 33N 77W		-2.3 12	-3.0 6	-1.0 9	0.5 14	-1.3 8	1.2 7	1.0 5	-.9 12	0.2 11	-.6 7	1.1 9	-1.7 10	-3.9 12	-4.0 9	-1.4 11	
11 32N 78W		-2.9 17	-1.2 5	-1.7 16	0.5 28	-1.8 13	-.6 14	-.5 11	0.4 12	-.2 14	-.9 11	-.4 14	-1.1 14	-3.0 8	-3.8 8	-1.0 16	
12 30N 80W		-2.7 12	1.1 17	0.6 15	-2.2 13	-1.2 10	-.7 7	0.4 136	0.2 190	-.1 200	0.4 37	0.8 21	0.4 10	-4.8 11	-.4 19	-1.7 17	
13 28N 79W		-1.8 14	-2.1 19	-.3 22	0.4 19	-.4 19	-.8 26	-.6 11	-.9 20	-.8 16	-.3 18	-.2 17	0.2 19	0.8 14	-.6 14	-.6 16	
14 26N 79W		-1.8 16	-1.6 14	-.2 30	-.0 27	-1.1 22	-.2 37	-.4 16	-.9 32	-.8 23	-.8 29	-.2 26	0.5 26	-1.2 16	-.8 23	-.5 26	
15 24N 80W		-1.2 14	-.6 13	0.1 18	0.4 18	-.1 22	-.3 21	0.1 12	-.6 17	-.1 21	0.7 20	-.2 19	-.6 15	-2.0 9	-.1 18	-.9 13	

SEA SURFACE TEMPERATURE MONTHLY ANOMALIES

Figure 7.—Anomalies of average monthly sea surface temperature (°C) from the 1948-77 mean for selected one-degree squares along the Atlantic coast. Approximate geographic location of squares is as follows: 1-Fundy, 2—Portland, 3—Cape Cod, 4—southern New England, 5—Long Island, 6—New Jersey, 7—Delmarva, 8—Virginia, 9—North Carolina, 10—South Carolina, 11—Georgia, 12—North Florida, 13—Canaveral, 14—Grand Bahama, 15—Florida Straits. Latitudes given are for the southeast corners of the one-degree squares. Open grid shading indicates positive anomalies of 1°C or more. Close line shading indicates negative anomalies of 1°C or larger. Small numbers in lower left corners of squares indicate the number of observations used in computing anomalies. Data display produced by NMFS Pacific Environmental Group, Monterey, Calif.

maximum, warm water from a band of Gulf Stream water encircling a warm-core eddy adjacent to the shelf edge was thrust under the resident bottom water raising the temperature to 17°C in the 50-60 m depth range. This is the highest bottom temperature observed at mid-shelf depths in the 1974-77 monitoring period.

Warm-Core Eddies

The most outstanding variation in the oceanographic conditions in the Middle Atlantic Bight during 1977 was the unusually large number of persistent warm-core Gulf Stream eddies, ranging from 40 to 150 n.mi. (70-270 km) in diameter, and moving westward and southward in the Slope Water along the edge of the continental shelf (Fig. 9). A summary of eddy activity in

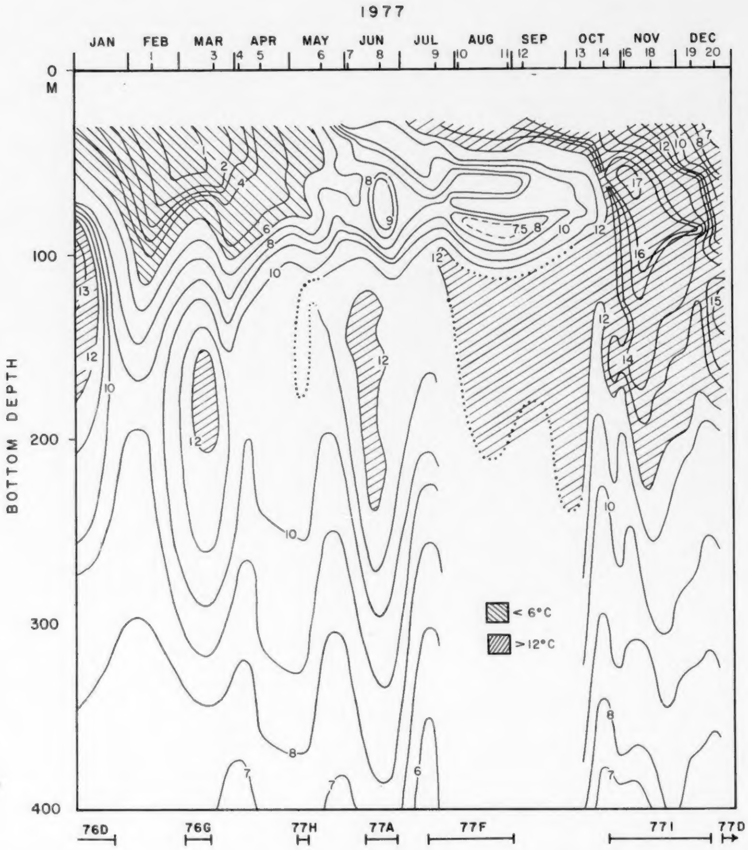


Figure 8.—Bottom temperatures on the continental shelf and slope south of New England during 1977. XBT sections are numbered along top. Dots mark the inshore and offshore bottom depth limits for each section. Horizontal lines at bottom of diagram indicate duration of warm-core Gulf Stream eddy passages south of New England.

The last of the 1977 eddies, 77D, formed in March, passed along the shelf edge off southern New England in January 1978 and was resorbed by the Gulf Stream east of Delaware Bay in the last week of February. From then until early May there were no warm-core eddies in the Slope Water, with curious consequences; the Shelf Water mass extended out much farther seaward, to the Gulf Stream edge in some places, overriding the Slope Water in a layer up to 50 m thick.

The unusual eddy activity in 1977 apparently led to loss of gear and poor catches for the lobster and crab fishermen working on the outer continental shelf and slope. The paths taken by the eddies (Fig. 10) shows that the potential for interaction in those waters was great. A compilation of 1977, compiled by Mizenko and Chamberlin[11] revealed that nine warm-core eddies formed during the year, eight of them in the first 4 months, and the ninth in July. In addition, three others which formed in 1976 continued to exist in the area in 1977. There were at least two eddies adjacent to the shelf edge between eastern Georges Bank and Virginia at all times during the year, and in May there were five present (Table 3). The lifespans of the eddies ranged from 37 to over 300 days with an average of about 150 days (Table 4).

[11]Mizenko, David, and J. L. Chamberlin. 1978. Gulf Stream anticyclonic eddies (warm-core rings) off the northeastern United States during 1977. Unpubl. rep., 23 p. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882.

Table 4.—Eddy formation and destruction dates and lifespans.

Eddy: Mizenko and Chamberlin[1]	Eddy: EOFA[2]	Dates[3]	Lifespan (days)
76D	H	5/20/76-2/6/77	262
76F	K	10/15/76-2/4/77	112
76G	J	10/27/76-5/26/77	201
77A	L	1/7/77-10/7/77	273
77B	M	1/26/77-(3/11/77)	44
77C	Q'	(2/12/77)-(5/18/77)	95
77D	Q	(3/20/77)-2/21/78	338
77E	N	4/10/77-10/12/77	185
77F	—	(4/11/77)-(5/18/77)	37
77G	Q	4/17/77-5/24/77	37
77H	P	4/25/77-9/5/77	133
77I	R	7/16/77-2/12/78	211

[1]See text footnote 11.
[2]Experimental Ocean Frontal Analysis charts produced weekly by the U.S. Naval Oceanographic Office.
[3]Dates in parentheses could be off by greater than a week. Dates not in parentheses are accurate to within a week and, generally, are accurate to within several days.

Table 3.—Eddy positions at mid-month with respect to zone during 1977.

Area	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
E. Nova Scotia		77B		77D	77D 77F	77D	77D					
W. Nova Scotia	77A		77C	77C	77C			77D	77D			
E. Georges Bank	76F	77A		77E	77G					77D		
W. Georges Bank	76G		77A		77E	77E		77I			77D	
Southern New England		76G		77A	77A	77A	77E		[1]77I	77I		77D
Long Island - New York Bight	76D		76G		77H		77A	77E	77E		77I	77I
New Jersey - Delaware				76G		77H	77H	77A	77A			
Virginia					76G			77H				

[1]Meander.

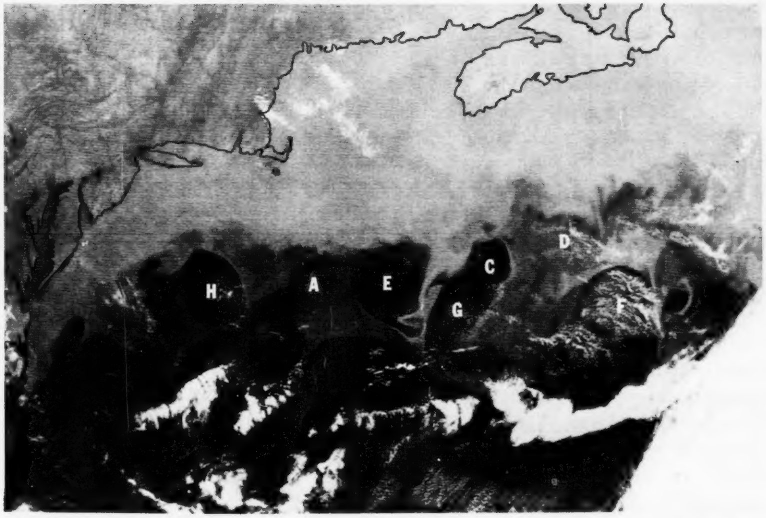
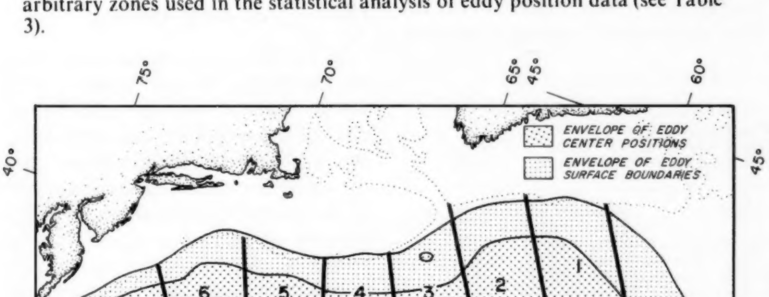


Figure 9.—The numerous warm-core Gulf Stream eddies that formed off northeastern North America during the first 4 months of 1977, as seen in infrared imagery from NOAA 5 environmental satellite on 30 April 1977. Warmer temperatures register darker. These clockwise rotating eddies, which are warmer than the water around them, are labeled alphabetically in the order that they detached from the Gulf Stream. During the balance of 1977, four of these eddies (A, E, G, and H), plus one more (I) which formed in July, moved westward and southwestward off the southern New England and Middle Atlantic Bights, and apparently caused strong currents at various times and places over the continental slope. The principal evidence of this eddy influence is from several deep-sea red crab and lobster fishermen, who reported that strong, persistent currents toward the east or northeast caused losses of gear and interference with fishing. Eddies C, D, and F were resorbed by the Gulf Stream before they reached the fishing grounds. Immediately south of the eddies the warm, meandering Gulf Stream is visible in the picture, although partly obscured by clouds. The coastline has been retouched to make its location clearly visible.

Figure 10.—Envelopes of surface boundaries and center positions of warm-core Gulf Stream eddies off the Atlantic shelf during 1977. Numbered areas are arbitrary zones used in the statistical analysis of eddy position data (see Table 3).



eddy locations and reports from lobster or crab fishermen in waters over the continental slope (<200 m) of gear loss, displacement, or surface float submergence has been made[12] and is summarized in Table 5. In addition, the eddies probably were responsible for the mixing of large volumes of outer Shelf Water and plankton into the Slope Water, as was evidenced by the frequent appearance of cooler Shelf Water entrained and wrapped around the eddies. During the absence of eddies in the Slope Water, the Shelf Water extended out, unmixed, developing an unusual two-layer structure with cooler, fresher water over warmer, saltier water.

Shelf Water Front

Gunn's (footnote 8) analysis of Shelf Water front positions from satellite charts for this area (Sandy Hook 130 transect, Fig. 5, 6) showed that in 1977 the front generally remained relatively close to the 1973-77 mean position. However, in the first 2 months of the year the front was about 40-70 km shoreward of its mean position along the shelf edge.

In the first quarter of 1978, the satellite infrared imagery revealed a spectacular displacement of the Shelf Water front offshore, beginning in February just 10 km from the shelf edge and moving out to 130 km by the first week in April. This anomalous displacement coincides with the unusual absence of warm-core eddies in the Slope Water region, suggesting a dynamic relationship between the eddies and the front or a mutual dependence of the two features on a common set of forcing functions.

An interesting result of this unusual offshore excursion of the Shelf Water was the apparent offshore diversion of migrating schools of Atlantic mackerel. The schools passed off Virginia about 20 n.mi. farther offshore than usual, generally escaping the domestic

[12]Chamberlin, J. L. Northeast Fisheries Center Atlantic Environmental Group, NMFS, NOAA, Narragansett, RI 02882, pers. commun.

fishing fleet, which was working nearer to shore.[13]

Anoxic Layer

The spring conditions in 1976 (early stratification, prevailing southwesterly winds, low storm incidence, and unusually heavy phytoplankton bloom) which led to the formation of an anoxic bottom layer in a large area of the subthermocline water on the shelf off New Jersey during the summer of 1976 were not repeated in 1977. Dissolved oxygen data collected from various ships for the MESA (Marine Ecosystem Analysis program) New York Bight Project in the spring and summer of 1977 revealed just a narrow band ($\geq$ 3 n.mi. wide) of low oxygen water nearshore along about 30 n.mi. (55 km) of the central New Jersey coast in late August.[14] Farther offshore, in the area which became anoxic the previous year, the dissolved oxygen levels remained above 2.5 ml/l.

South Atlantic Bight

Temperature Structure

Except for meteorological data, satellite imagery, and sea surface temperature data (collected from ship intakes), no routine monitoring information presently is available to us from the South Atlantic Bight. The temporal-spatial patterns of sea surface temperature anomalies (Fig. 7) show extensive patterns of cold anomalies in January-March of both 1977 and 1978. In both years the anomalies were most intense off South Carolina and Georgia. In 1978 the cold anomalies were not as intense off Florida as they were the previous winter.

During the spring and summer months of 1977 the waters of the South Atlantic Bight did not experience the anomalous warming which occurred in the Middle Atlantic Bight. In fact, a considerable portion of the former continued to show negative SST anomalies throughout the period.

Gulf of Mexico

Temperature Structure

The sea surface temperature data set available for the Gulf of Mexico does not provide good areal coverage and replication. The observations are most numberous along shipping lanes from either the Yucatan Channel or Florida Straits to major ports from Mobile, Ala., to Corpus Christi, Tex., and absent in the northeastern and southwestern Gulf. Nevertheless, in the area covered, seasonal changes are apparent in the data set for 1977 and early 1978.

In January and February 1977 negative SST anomalies, up to -3.7°C in magnitude, were found in virtually all of the coastal 1° squares monitored. In March this pattern moderated considerably in the eastern Gulf, but persisted in the western half. In April, both halves were experiencing nearly normal sea surface temperatures with weak positive or negative anomalies showing in most squares. This period of normalcy lasted until October, when strong negative anomalies appeared in the eastern Gulf. This condition disappeared in November, but reappeared in January, began spreading westward in February, and occurred in both halves in March 1978. The magnitudes of the cold anomalies in 1978 were only slightly less than in 1977, but the anomalous region was more extensive and more persistent in 1978.

The variation of coastal sea surface temperatures in both winters clearly was a reflection of atmospheric events, as indicated by the coastal air temperatures (Table 1). Here also, anomalies in early 1978 were only of slightly lesser magnitude than in 1977, but were more widespread and persistent. Comparing the air and sea temperature records for March and April also reveals a lag time of about 1 month for the warming of the sea surface, as is to be expected.

The prolonged cool temperatures in early 1978 apparently have had an effect on at least one marine resource organism, the brown shrimp, in the western Gulf. Growth in this animal has been noticeably retarded this season.[15]

Eastern Gulf Loop Current

In his efforts to summarize the state of knowledge of the Eastern Gulf Loop Current and to describe its configuration in 1977 and early 1978, Brucks (footnote 15) has found that the classical generalized seasonal cycle of the current has recently come under scrutiny (Behringer et al., 1977). The cycle of maximum northward intrusion into the Gulf in spring and summer and minimum intrusion in fall

[13]Austin, H. M., Virginia Institute of Marine Science, Gloucester Point, VA 23062, pers. commun.

[14]Swanson, R. L., MESA New York Bight Project, SUNY, Stony Brook, NY 11794, pers. commun.

[15]Brucks, J. T., National Fisheries Engineering Laboratory, NMFS, NOAA, Bay St. Louis, MS 39520, pers. commun.

Table 5.—Gulf Stream eddies associated with reports by deep sea red crab and lobster fishermen of strong currents interacting with fishing gear over the continental slope off the southern New England and Middle Atlantic coasts during 1977.

Eddy[1]	Date	Area	Fishing gear
77H	Last week of June to third week of July	Between Baltimore and Washington Canyons	Red crab Lobster
77A	First to third weeks of September	Between Baltimore and Washington Canyons	Red crab Lobster
77E	Sept. 2-3	East of Hudson Canyon	Red crab
77I	Nov. 20-Dec. 4	East of Hudson Canyon	Red crab Lobster
77G	Third and fourth weeks of December	Between Atlantis and Block Canyons	Lobster

[1]Eddies listed in their order of entering the region off southern New England and designated by their year of formation and alphabetically in their order of formation.

and winter has not held up in the light of recent studies. Satellite infrared imagery and winter cruise data have revealed instances of major intrusions in the winter months. A case in point is the cycle observed in plots produced by the NESS Field Service Station [16] in 1977 and early 1978, shown in Figure 11. Maximum intrusion in the 15-month period occurred in February 1977 and another slightly inferior maximum occurred in January 1978. A minimum was detected in the summer and fall periods using cruise data because satellite viewing conditions are degraded then because of poor contrast due to surface heating.

The current's trajectory takes it into the Gulf northward from the Yucatan Channel, occassionally as far as the outer shelf off the Mississippi-Florida coast, then eastward and southward along the shelf off western Florida, then out through the Straits of Florida. Variations in its strength and extension northward into the Gulf must strongly influence the environment of the biota of the continental shelf, as well as the distribution of the pelagic species associated with the current itself.

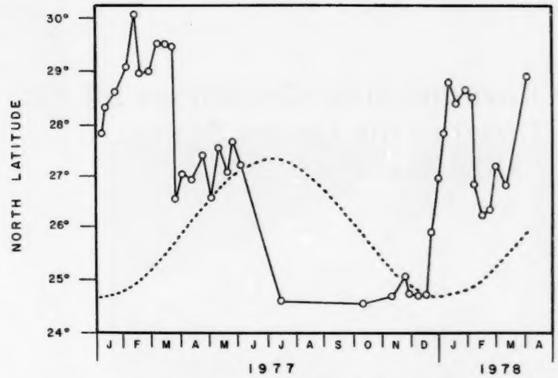


Figure 11.—Northward extension of the Eastern Gulf Loop Current into the Gulf of Mexico during January 1977-March 1978, based on sea surface frontal charts produced by the NESS Satellite Field Service Station in Miami, Fla. Dashed line curve represents the generalized annual cycle of extension of the current (from Behringer et al., 1977).

Mississippi River Discharge

Flow data for the Mississippi River at Tarbert Landing,[17] reveal a long-term (1963-76) average cycle of high flow in March-May, with the average maximum of about 720,000 cubic feet per second in April and low flow in August-November, with the average minimum of about 200,000 cubic feet per second in September. The flow pattern in 1977 was below average during the normally high flow period, with record lows in February and June, and above average during most of the normally low flow period and extending into December.

[16]Satellite Field Service Station, NESS, NOAA, P.O. Box 8243, Coral Gables, FL 33124.

[17]Computed by the U.S. Corps of Engineers Regional Office at New Orleans, La.

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Marine Environmental Conditions off the Pacific Coast of the United States, January 1977-March 1978

D. R. McLAIN, F. FAVORITE, and R. J. LYNN

Introduction

During 1977 and early 1978 unusual atmospheric circulation occurred over the northeast Pacific. In both winters (1976-77 and 1977-78) strong and persistent high pressure ridges in the atmospheric circulation formed over the west coast of North America. The atmospheric circulation had a variety of effects on local oceanographic conditions and fishery resources in the region.

As a result of the ridge circulation during both winters, southerly winds of moist, warm air blew over Alaska and the eastern Bering Sea. This caused the coastal waters of the southeastern Bering Sea and the western Gulf of Alaska to be much warmer than normal. The warm weather broke a 6-year cold spell (1971-76) which had had serious effects on fisheries in the Kodiak Island region and the southeastern Bering Sea. The warm waters of 1977-78 should allow rapid growth of juvenile salmon, halibut, and other species. Herring spawning may be advanced by 1-2 weeks. Abundant precipitation fell over Alaska. Wind driven surface transport caused surface waters to be held near the coast of the Gulf of Alaska. This convergence combined with the dilution from precipitation and runoff to increase coastal longshore circulation in the Gulf. Increased advection of waters from the south transported salpae into waters off southeastern Alaska in May and June 1978.

Off the west coast of the contiguous United States, the circulation associated with the atmospheric pressure ridges was dissimilar in the two winters. During the winter of 1976-77, a high pressure system persisted off the California coast which diverted storms to the north. Calm, clear weather under this high pressure system produced record drought over California and warmed coastal waters. Upwelling off the California coast was moderate.

In contrast, during the winter of 1977-78 the ridge over Alaska moved northwestward, the high pressure system off California was absent, and a weak trough occurred off the west coast. The trough allowed storms to come into the coastal zone and bring abundant precipitation to California, breaking the drought. Airflow was more southerly than normal causing coastal convergence and possibly increased flow of the Davidson Current. Occasional strong downwelling pulses occurred. The coastal convergence broke a 5-year run of strong upwelling. Due to the convergence and to possibly increased Davidson Current, coastal waters were again warmer than normal. Also due to the coastal convergence, eggs of winter spawners such as anchovy would have been held nearer the coast than normal and may result in better than normal survival.

Cooler than normal water occurred throughout the period in an extensive area of the central North Pacific near lat. 40°N and long. 150°W. Strong winds over this region during the winter of 1976-77 appear to have strengthened the transport of the West Wind Drift Current. Low salinity water occurred in the California Current during 1977 and especially so in 1978, suggesting anomalously great advection of low salinity, subarctic water from the north and increased local precipitation. Associated with this change was a weakening of salinity fronts of the Transition Zone in 1977. Fronts in the Transition Zone in early 1978 were near normal.

Sea surface temperatures in the eastern tropical Pacific decreased during early 1977 from the anomalously high temperatures that resulted from a moderate El Niño in 1976. Sea surface temperatures were lower than normal off Peru and along the Equator from April to September 1977 and during early 1978, possibly due to increased upwelling. Temperatures off Baja California were above normal in early 1977 due to excess solar insolation and were again above normal in early 1978 due to weak upwelling. Wind mixing and tropical storms reduced surface water temperatures along the coast of Central America during 1977 and early 1978. Strong winds and the response of tuna fishermen to porpoise regulations contributed to below normal tuna catches during 1977.

Atmospheric Variations

The dominant feature of the atmospheric circulation over the northeast Pacific Ocean during January 1977 to March 1978 was the presence during the winters of 1976-77 and 1977-78 of persistent and intense ridges of high atmospheric pressure over the west coast of North America. The January circulation, as depicted by the heights of the 500-mb pressure surface, is

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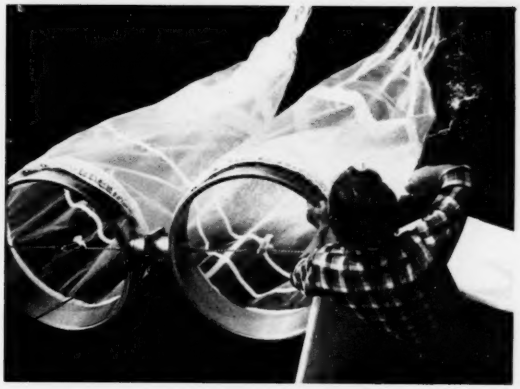
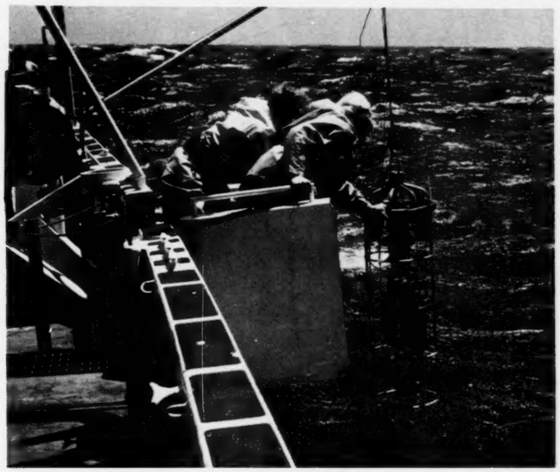




Fishery technicians (left and right above) launch instruments to measure oceanographic conditions. Temperature and salinity variations reveal such important ocean processes as upwelling, ocean front formation, and current changes. Yellowfin tuna (bottom right), ranging across broad reaches of the eastern tropical Pacific Ocean, are sensitive to specific ranges of temperature and oxygen. Fishermen monitor the vertical ocean temperature structure as an important tactic in fishing for them.

representative of each winter (Fig. 1). The upper air ridges resulted in the advection of warm, maritime air northward over the northeast Pacific and bought southerly winds and mild conditions to the south coast of Alaska. A persistent blocking high pressure cell was present off California during much of 1977 and diverted storms to the north. During the winter of 1977-78 the ridge structure was expanded and shifted to the northwest over Siberia and Alaska and a weak low pressure trough was present off the west coast. Southwesterly winds associated with this trough then brought storms onto the west coast of the United States. Downstream from the persistent ridges along the west coast northerly winds blew over the eastern United States, producing record cold and snowy winters. The ridges in both winters were somewhat similar to the ridge that occurred during the winter of 1957-58 which brought warm coastal waters to much of the west coast of North America and cold weather to the eastern United States (Johnson and McLain, 1975). Namias (1978) described the unusual atmospheric circulation of the winter of 1976-77, its relations to ocean conditions, and multiple causes for its formation.

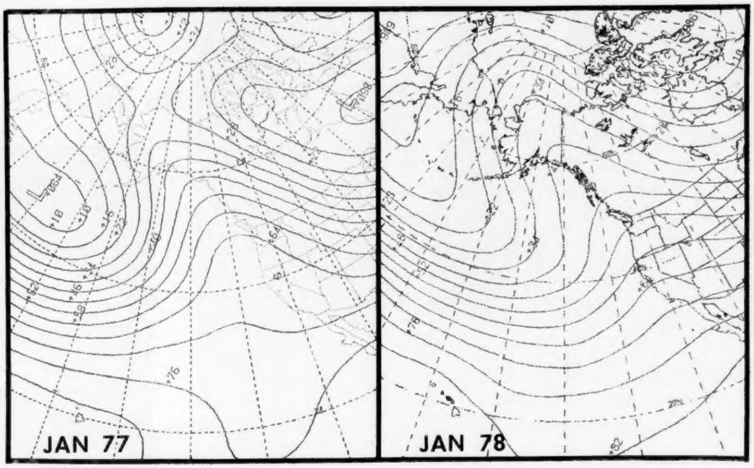


Figure 1.—Heights of 500-mb pressure surface (in tens of meters, +5,000 m) in January 1977 and January 1978. Contour lines are at 60-m intervals.

At the ocean surface, beneath the ridges of upper air circulation, the distribution of surface barometric pressure indicates the surface winds which drive the ocean currents. Figures 2, 3 show the surface pressure patterns and winds over the Northeast Pacific during the winters of 1976-77 and 1977-78 (January data are again taken as representative). The Aleutian low pressure system is the dominant winter feature of the surface circulation over the North Pacific and in both winters the Aleutian low was deeper than normal (Fig. 2, 3, lower). This anomaly of low pressure had been characteristic of the last quarter of 1976 and lasted through February 1977. The anomaly pattern became reestablished in January 1978 and lasted through April.

During the 1976-77 winter the normally weak high pressure cell of California was elongated and extended northward over Oregon, Washington, and British Columbia (Fig. 2, upper). The resulting intensified atmospheric circulation advected warm maritime air toward the southern Alaska coast where record mild temperatures and abundant rainfall occurred. Under the high pressure cell, winds were weak, clear weather prevailed, and record drought occurred in California.

In the winter of 1977-78, a deepened Aleutian low extended far to the east of its normal position and the high pressure cell off California was absent (Fig. 3, upper). This circulation directed storms over the west coast of the United States and resulted in record or near record rainfall, breaking the California drought. During the intervening seasons, barometric pressure patterns and associated winds were closer to normal than during the winters.

Gradient and Vector Winds

The relative intensity and direction of surface winds over the northeast Pacific during the winters of 1976-77 and 1977-78 is shown by isolines of surface barometric pressure and their gradients (Fig. 2, 3). Also shown in the figures are arrows, which in the upper half of the figures represent the direction of resultant average vector winds and in the lower half of each figure represent the departure of each vector wind from its long-term average.

The westerly winds south of the deepened Aleutian low were stronger than normal west of long. 150° W in the last quarter of 1976 and first 2 months of 1977 (e.g., January 1977, Fig. 2). Between long. 130° and 150° W there was a strong southerly component to the winds and the general marine conditions were characterized by high winds, high seas, and storms. East of long. 130° W, conditions were relatively mild. By March the subtropical high pressure cell off California had intensified, producing strong northerly winds along the coastal region and causing a strong pulse of coastal upwelling from Baja California northward to Alaska. Winds were near normal over extensive areas of the eastern North Pacific Ocean through July. For 3 months beginning in August the Aleutian low alternated between a deepened and relaxed condition in the area west of long. 135° W. East of long. 135° W winds were near normal. In December, a southeastward shift of the Aleutian low and a weakening of the high pressure cell brought southerly moist winds to the California coastal regions.

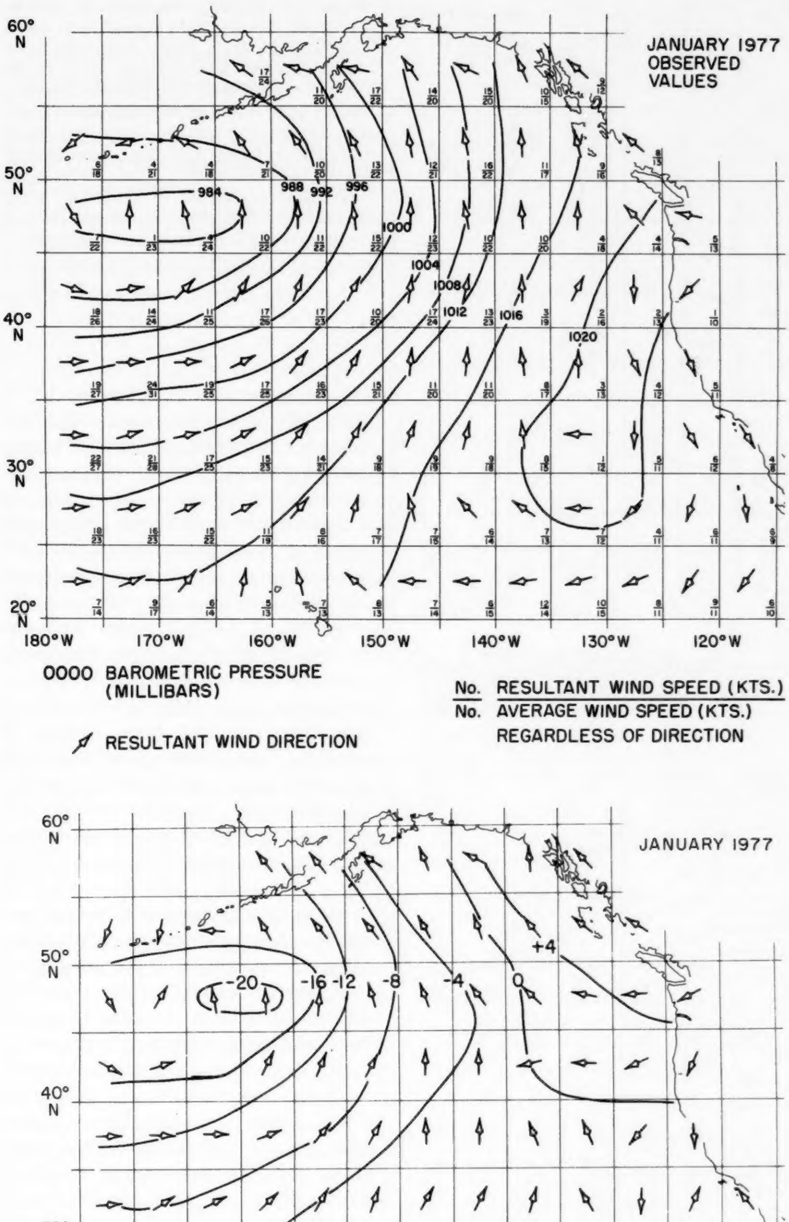


Figure 2.—Upper—Sea level barometric pressure (millibars), resultant wind direction (degrees true), resultant wind speed (knots), and average wind speed (knots) regardless of direction for January 1977 (from *Fishing Information*). Lower—Departure of sea level pressure (millibars) from the long-term mean (calculated from 1961 through present year) and departure of resultant wind direction from long-term mean for January 1977 (courtesy of J. Renner).

Ocean Surface Transport and Upwelling

The polar easterlies, mid-latitude westerlies, and subtropic easterlies (trades) are terms describing long-term averages of prevailing winds over the oceans. Beneath these zonal regions of winds lie the major ocean currents that flow over great distances in much the same direction as the winds. In the northeast Pacific the major wind driven currents are the West Wind Drift Current, the Alaskan Stream, the California Current, and the North Equatorial Current. The surface layer transports associated with these currents has been computed from classical Ekman theory based upon monthly average wind data.[1] Although Ekman transport estimates form only a portion of the total ocean circulation, they suggest the monthly and seasonal influence of the winds. The 20-year averages of monthly transports at each of four selected locations in the northeast Pacific during 1977 and early 1978 are shown in Figure 4.

In the offshore region (e.g., lat. 39°N, long. 149°W; Fig. 4, lower), strong westerlies in winter strengthen the West Wind Drift. At lat. 27°N, long. 140°W subtropic easterlies may strengthen the North Equatorial Current in summer. During January and February of both 1977 and 1978

[1]Computations of surface layer transport prepared by Andrew Bakun, Pacific Environmental Group, NMFS, NOAA, Monterey, CA 93940. Values are computed on a grid of 3° latitude and longitude from data of Fleet Numerical Weather Central, Monterey, CA 93940.

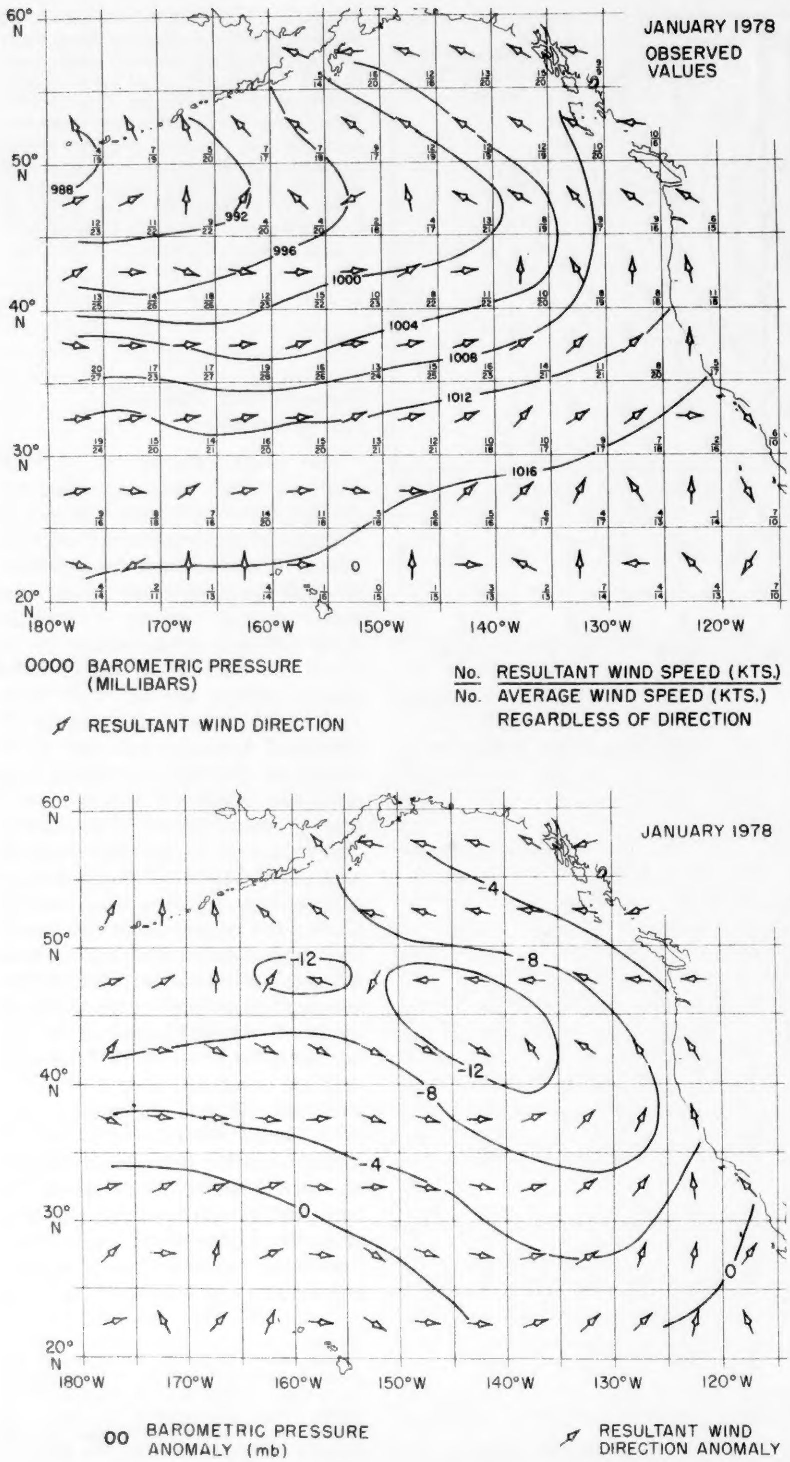


Figure 3.—Upper—Sea level barometric pressure (millibars), resultant wind direction (degrees true), resultant wind speed (knots), and average wind speed (knots) regardles of direction for January 1978 (from *Fishing Information*). Lower—Departure of sea level pressure (millibars) from the long-term mean (calculated from 1961 through present year) and departure of resultant wind direction from long-term mean for January 1978 (courtesy of J. Renner).

(Fig. 4, upper) transport at lat. 39° N, long. 149° W was very large and directed to the southeast. At lat. 27° N, long. 140° W where southeast winds normally drive the waters to the north, the transport for the same time periods was weak or southward. Thus in both winters and over a broad offshore region, the winds acted to intensify the West Wind Drift Current and the southeastward flow of the California Current. Low salinities in the California Current (discussed in a later section) may have, in part, been a result of greater than normal intrusion of subarctic waters, caused by strengthened advection. Transport during the intervening months was near normal with the exception of March 1977 at lat. 27° N, long. 140° W when the intensified subtropical high strengthened the southeast trades, producing large transport toward the northwest.

Along the coast, surface transport moves water onto or away from the coast and causes vertical movements of water known as upwelling (or downwelling)—a process of great biological significance. The northwest winds prevailing in summer along the coast from Oregon southward to Baja California (e.g., lat. 39° N, long. 127° W) cause surface transport offshore and replacement by cold, nutrient rich water upwelled from below. The nutrients in this water support the abundant biological productivity in the area. Along the Alaska coast (e.g., lat. 57° N, long. 140° W) transport is onshore during much of the year.

Onshore-offshore transports also affect the strength of coastal currents.

The effect of upwelling (and downwelling) forces a compensatory flow elsewhere in the water column which affects the density structure (baroclinicity) and, hence, geostrophic flow. In periods of increased coastal upwelling where there is anticyclonic flow (i.e., California Current) the flow is strengthened, and in periods of increased coastal downwelling where there is cyclonic flow (i.e., Alaskan Stream) the flow is similarly strengthened.

Transports computed for 1977 and early 1978 for the coast of northern California at lat. 39° N, long. 128° W show that there was anomalous offshore transport during March, June, and July 1977 and anomalous offshore transport during December 1977 through February 1978. Thus during March, June, and July there was increased upwelling and, possibly, a strengthened California Current near the coast. During the subsequent winter there was downwelling and possibly a stronger nearshore countercurrent. During a typical winter, the current seasonally weakens and shifts away from the coast while the poleward flowing California Undercurrent surfaces as a countercurrent (Davidson Current) in the near-coastal regions. In the subject winters each of these events may have been enhanced. One consequence of the onshore transport during early 1978 would have been to hold eggs and larvae of winter spawning fish such as anchovy closer to the coast than normal. This may be desirable for good survival.[2]

In the Gulf of Alaska at lat. 57°N, long. 140°W, winds during both winters acted to strengthen the normal seasonal onshore transport, strengthen coastal downwelling, and probably also enhance westward geostrophic flow in the Gulf of Alaska. The abundant precipitation of both winters caused dilution of coastal surface waters in the area and probably acted to further strengthen the enhanced

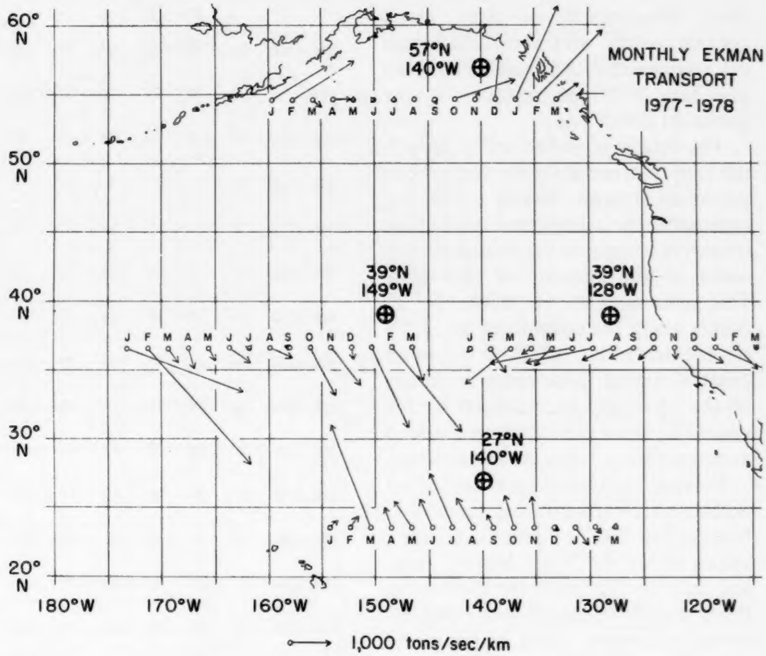
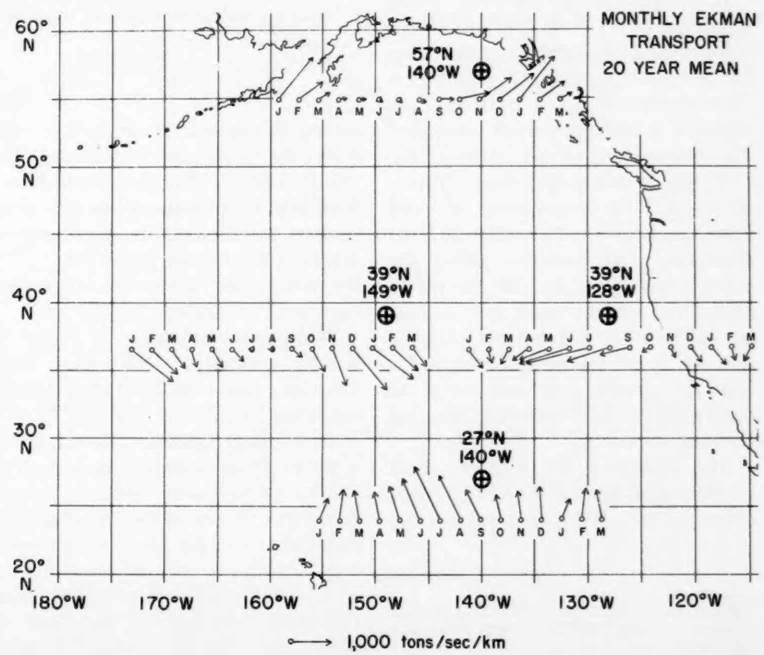


Figure 4.—Vectors of monthly Ekman transport for four areas of the eastern North Pacific, computed over a 3° square of latitude and longitude for January 1977 through March 1978 (upper) and for monthly means over a 20-year period (lower).



[2]Parrish, R. H., and C. S. Nelson. 1976. Larval transport mechanisms in the California Current. Presented at California Cooperative Oceanic Fisheries Investigations Conference, Indian Wells, Calif., November 16-18, 1976.

flow. Observations of clear, warm oceanic waters with abundant salpae off southeastern Alaska during May and June 1978[3] are explained by the increased flow.

The details of variations of upwelling with distance along the coast are of particular interest. Bakun (1973) has computed the component of Ekman transport normal to the coastline as an index of the intensity of upwelling. This computation is made at 15 points along the coast from lat. 21°N off Mexico to lat. 60°N on the south coast of Alaska. Time-space variations of the upwelling as indicated by the upwelling index are shown in Figure 5 as percentiles of historic normal values.

Very strong upwelling occurred off northern California during January to November 1977. Upwelling index values at lat. 39°N for March, June, and July of 1977 were the highest for those months in the 32-year (1946-77) period of record. Only in May and after November did the values at lat. 39°N fall below the median for the month. Thus 1977 continued an unprecedented series of 5 years of strong upwelling off northern California which had begun in 1973.

In contrast to the generally strong upwelling of 1977, during early 1978 downwelling occurred along the California coast as previously mentioned. This downwelling is indicated on Figure 5 as extremely weak upwelling. The downwelling period broke the run of 5 years of strong upwelling mentioned above. The downwelling or weak upwelling began in December 1977 off California and extended along the entire coast from lat. 24° to 60°N, except for a minor peak in March at lat. 45° to 48°N. Off central California (lat. 30° to 36°N) the upwelling index was the lowest that had occurred during the period of historical record at 6 month-locations.

The upwelling off southern Baja California (at lat. 21°N and to a lesser extent at lat. 24°N) was persistently strong throughout the period. During February to August, upwelling index values at lat. 27°N and southward have been in or near the upper quartile of the various month-location distributions. At the southermost point (lat. 21°N) the index was in the 95th or higher percentile throughout the period.

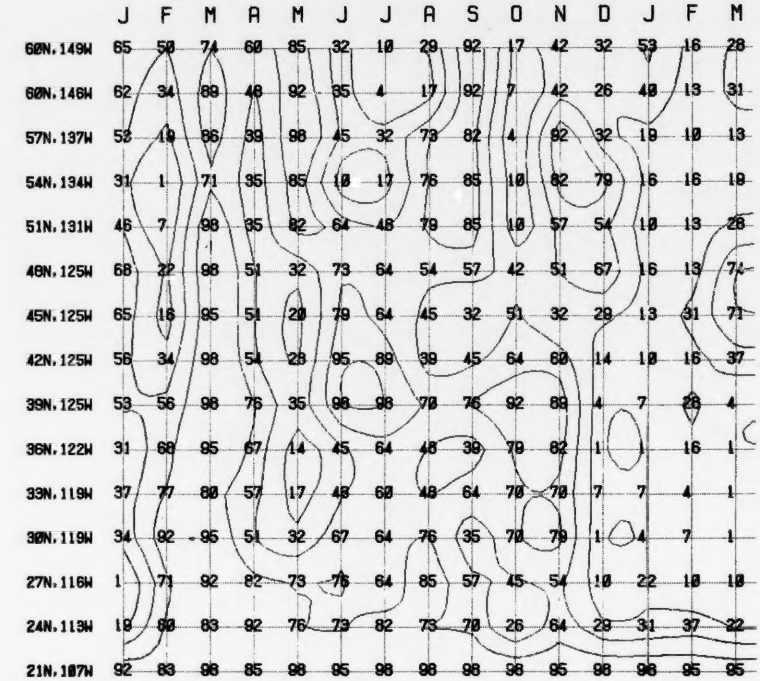


Figure 5.—Monthly upwelling index values for January 1977 to March 1978, in percentiles of the frequency distributions made up of the 32 values for each month and location in a 32-year (1946-77) time series. Locations in the Gulf of Alaska are toward the top of the figure; those off Baja California are toward the bottom. The contour interval is 25 percentiles. Values above the 50th percentile indicate stronger than normal upwelling while those below indicate weaker than normal upwelling.

Widespread anomalies occurred in March and May 1977. Very high upwelling index values during March extended south of lat. 21°N off southern Baja California to lat. 60°N in the northern extremity of the Gulf of Alaska (where they indicate abrupt relaxation of the winter downwelling situation). During May, values were very low from off the Washington coast southward to northern Baja California but high in the Gulf of Alaska and off southern Baja California.

Sea Surface Temperature

Over the North Pacific, sea surface temperature (SST) increases predominately from north to south (Fig. 6). The nearly zonal pattern of isotherms of SST over the North Pacific mid-latitudes is deflected near the west coast by advection and upwelling. There is a northward bending of isotherms into the Gulf of Alaska and a southward bending from Oregon to Baja California. The deflection is greatest in summer months.

Over much of the open ocean in temperate latitudes the annual minimum in SST is reached during March (Fig. 6, upper) and the maximum is reached during September (Fig. 6, lower). The amplitude of the seasonal variation of sea surface temperature ranges from a high of about 10°C in

[3]Bruce L. Wing, Northwest and Alaska Fisheries Center, NMFS, NOAA, Auke Bay, AK 99821, pers. commun.

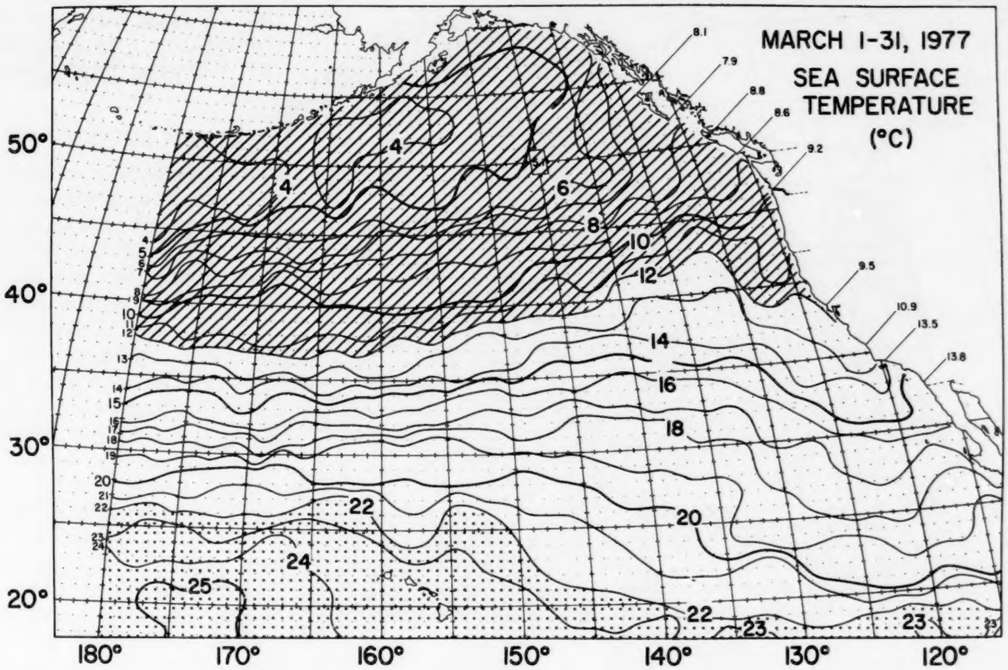
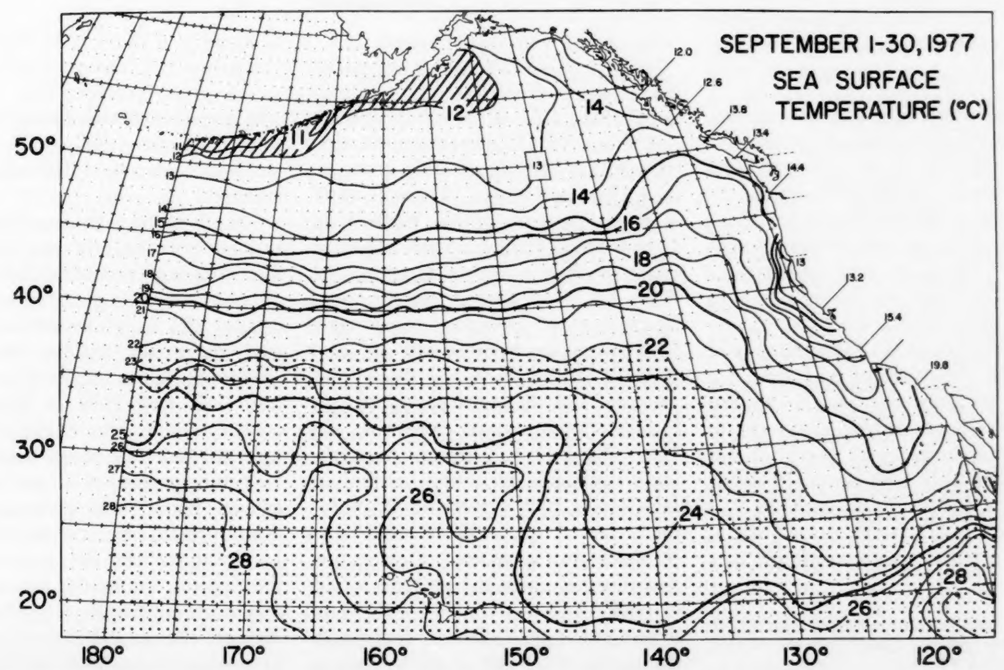


Figure 6.—Sea surface temperature for the eastern North Pacific during March 1977 (upper) and September 1977 (lower), adapted from *Fishing Information.*



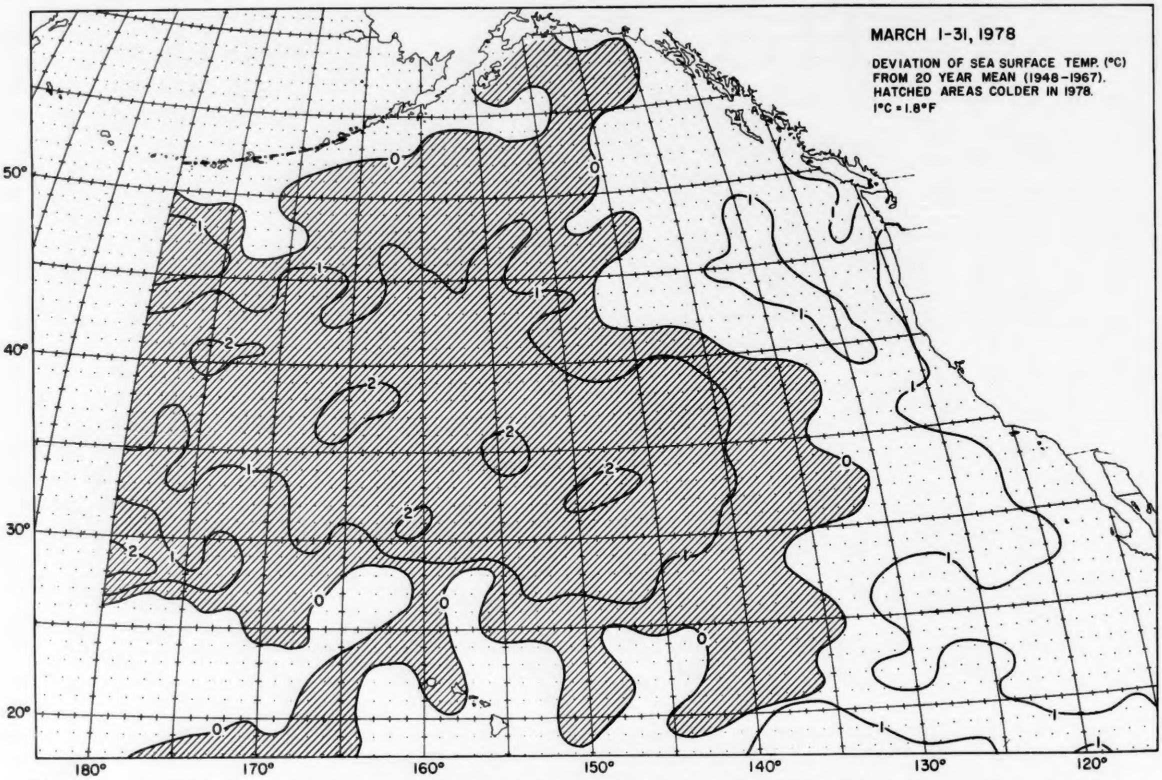


Figure 7.—Anomaly of sea surface temperature (°C) for March 1978 from the 20-year monthly mean (1948-67). Hatched area was colder in 1978 than long-term mean (from *Fishing Information*, March 1978).

the mid-latitude zone where the meridional temperature gradient is greatest to 8°C in the Gulf of Alaska and 5°C in the subtropics. In the coastal region the amplitude of variation is much reduced by upwelling of cool waters during summer (Oregon and south) and slightly reduced by downwelling in winter along the Alaska coast.

Contoured charts of the anomaly of SST (the departure of SST from the 20-year monthly mean) for the eastern North Pacific are published monthly in *Fishing Information.*[4] In all but 1 of the 15 monthly SST anomaly charts published for 1977 and early 1978, a large body of cooler-than-normal water appeared roughly centered in a band along lat. 40°N between long. 175°E and 150°W. (The chart showing this feature for March 1978 is reproduced here as Figure 7.) Latitude 40°N is about the axis of the West Wind Drift Current and the latitude of a large north-south gradient in temperature. Eber (1971) described the frequent occurrence of persistent large-scale SST anomalies between lat. 30° and 50°N in the North Pacific Ocean and proposed that they were produced by a quasi-stationary wave pattern in the West Wind Drift Current. A southward displacement of the Current in mid-Pacific and northward displacement east of long. 150°W could have produced, in a gross sense, the negative temperature anomaly pattern found during 1977 and early 1978. The development of this feature had begun during the latter half of 1976, hence it was a phenomenon having a longer time scale than that of the monthly variations in wind-induced Ekman transport.

Details of the variation of sea surface temperature along the coast are discussed later for individual sections of coastline. In general, however, coastal SST variations were characterized by broad regions of positive anomalies during the early months of both 1977 and 1978. In March 1977 coastal regions were near normal and by April they were cooler than normal. For the remainder of the year the coastal region was generally cooler than normal, especially in November. In December there was a relaxation of the negative anomalies and an excessive warming off Baja California. By January the coastal region from Baja California to southeastern Alaska was

[4] *Fishing Information*, published monthly by Southwest Fisheries Center, NMFS, NOAA, La Jolla, CA 92038.

again warmer than normal. The positive anomaly grew in magnitude and extent through March 1978 (Fig. 7).

Eastern Bering Sea

The Bering Sea is a deep ocean basin separated from the open North Pacific Ocean by the Aleutian Island Chain. In the eastern portion of the basin there are extensive areas of shallow water supporting abundant fishery resources. The oceanography of the shallow areas is dominated in the winter and spring by the extent and duration of ice cover and in spring and summer by heating and river discharge. Fast moving, intense storms originating in the North Pacific Ocean as well as locally have major effects on ice cover, runoff, and ocean currents.

Oceanographic data from the area are scarce and there are relatively few routine observations of oceanographic conditions due to the remote location and to winter ice cover. Air temperature records at weather stations, river discharge measurements, and scattered observations at a few coastal stations are the only long-term data available.

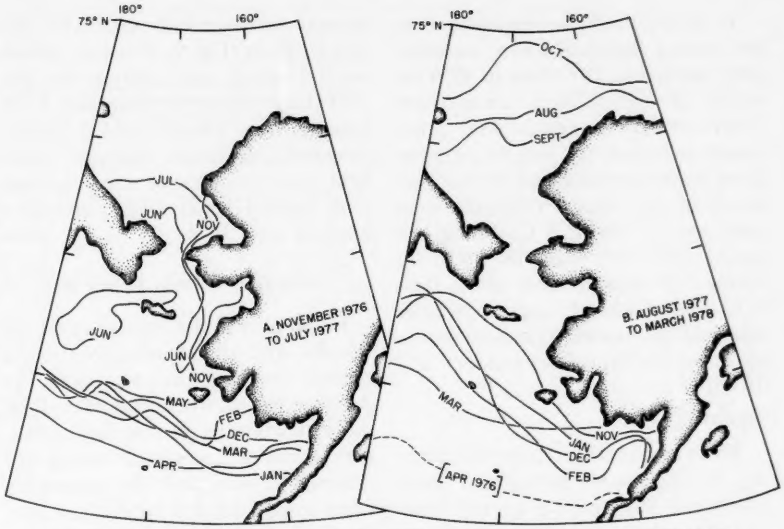


Figure 8.—Mid-month locations of ice front in eastern Bering and Chukchi Seas during November 1976 to March 1978 and, for comparison, April 1976. Plotted from data of the National Environmental Satellite Service and from ice cover analyses from U.S. Navy Fleet Weather Central, Suitland, Md.

Ice

The extent of ice cover in winter and the timing of ice breakup in spring are important environmental factors affecting fishes and fisheries in the eastern Bering Sea. Satellite infrared imagery and weekly charts of ice distribution issued by the U.S. Navy and National Environmental Satellite Service (NESS) provide information on ice conditions in the eastern Bering Sea. A graphical representation of the mid-month positions of the ice edge, based on the Navy and NESS data, is shown in Figure 8 for the ice seasons of 1976-77 and 1977-78. For comparison, the position of maximum ice extent during the previous season (1975-76) is also shown on Figure 8. Overall, ice cover was above normal in winter and spring 1977 and normal or even slightly above normal in late fall 1977, but below normal during the winter of 1977-78. Only small amounts of ice remained in embayments on the north side of Bristol Bay in late March. In addition, the breakup of lake ice in the area is expected to be early.

Temperature

Air temperatures over the eastern Bering Sea during 1977 and early 1978 were generally warmer than normal as a result of southerly winds associated with the persistent high pressure ridges in the upper air circulation. Anomalies of air temperature at St. Paul Island in the Pribilofs were positive in 8 out of 13 months in which data were available in 1977 and early 1978 and ranged up to 4.1°C above normal. Temperatures farther north along the coast at King Salmon, Nome, and Kotzebue also were generally above normal, particularly in early 1977 and early 1978. In January 1977, King Salmon, Nome, and Kotzebue all observed air temperatures 9° to 11°C above normal. This was the warmest January on record at King Salmon and Nome.

Thus 1977 and early 1978 broke a stretch of 6 years (1971-76) in which temperatures in the southeastern Bering Sea were much below normal. Stocks of such marine species as sockeye salmon and halibut were adversely affected by the cold years (McLain and Favorite, 1976). The warm conditions of 1977-78 should allow more rapid than normal growth rates of salmon and halibut in the Bering Sea and of juvenile salmon in tributary streams and lakes.

The water of the eastern Bering Sea is isothermal during winter with temperatures throughout the water column during winter of -1.8°C under the ice and 1°-3°C just north of the Alaska Peninsula, depending on the southern extent of the ice cover. Warming in spring and summer of the surface layer closely parallels increasing air temperatures, but dilution from ice-melt and rapidly increasing land runoff quickly stabilizes the water column and confines further warming to the upper 20-30 m. Thus, bottom temperatures generally reflect the extent of ice cover until late summer and early fall when horizontal advection and downward diffusion of heat can increase bottom temperatures prior to winter overturn and seasonal ice formation.

In general, bottom temperatures in the eastern Bering Sea were considerably warmer in 1977 than in 1976 (or much of the 1970's). Data from NMFS research surveys[5] and other vessels indicated that bottom temperatures in the corridor into Bristol Bay north of the Alaska Peninsula were near normal (about 3°C) during late spring and early summer 1977. In spring 1976 temperatures of less than 0°C had occurred and apparently hindered the eastward onshore movement of halibut (Favorite et al., 1977:151[6]).

Runoff

There are six major rivers discharging into the eastern Bering Sea. These rivers and their average annual flows (100,000 cubic meters per second) are: Yukon (17.6), Kuskokwim (4.6), Kvichak (0.4), Kuzitrin (1.3), Wood (0.6), and Nuyakuk (0.6). Although ice jams in spring (not only in the rivers but at the river mouths) influence the freshwater discharge from the extensive snowsheds, ice breakup usually occurs in the low flow lowland rivers (Egegik, Naknek) by mid-April, in the Kuskokwim Bay by 1 May, and the entrance to the Yukon River by early June.[7] In May, the mean daily discharges of most rivers increase an order of magnitude (e.g., for the Yukon River from about 700 to 17,000 cubic meters per second and for the Kuskokwim River from 300 to 2,800 cubic meters per second); maximum values have been maintained at times until summer.

Although runoff data were only available through September 1977 at the time of this report, generally normal discharge had occurred in the Yukon River (Fig. 9). However, above normal runoff was apparent for the Nuyakuk River in summer 1977 because local rainfall added to the snowmelt discharge. Reports from field personnel indicate above normal rain, ground water tables, and lake levels in early 1978.

Aleutian Islands to Icy Bay

Flow along the south coast of Alaska and the Alaska Peninsula moves southwestward toward the Aleutian Islands where part of the flow moves northward into the Bering Sea, part continues westward along the Aleutian Chain, and the remainder turns southward and recirculates into the Gulf of Alaska.

Ice

Ice conditions in Prince William Sound and Cook Inlet were mild in both winters 1976-77 and 1977-78 and most bays were ice free by March of eacy year.

Temperature

Observations at coastal weather stations on the south coast of Alaska indicate that air temperatures were above normal in early 1977 and early 1978 but were near normal or below normal in mid and late 1977. Air temperatures were up to 3°C above normal at Cold Bay and Kodiak and 1° to 8°C above normal at Homer and Yakutat in January and February of both 1977 and 1978.

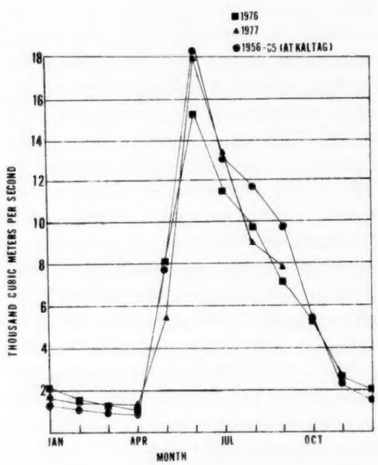


Figure 9.—Discharge of Yukon River at Pilot Station for 1976 and 1977 and 1956-65 long-term mean at Kaltag in thousands of cubic meters per second. Data from U.S. Geological Survey.

Sea surface temperatures[8] along the coast from the eastern Aleutians to Icy Bay (Fig. 10) normally range from minimum values of 3°-6°C in January to March to maximum values of 9°-14°C in August or September. Winter minima are lowest in the Kodiak Island and Alaska Peninsula areas while summer maxima are greatest off Prince William Sound and to the east.

Throughout the period January 1977 to March 1978 SST's (Fig. 11) were generally higher than normal along the entire coastline from the eastern Aleutian Islands to Icy Bay. Water temperatures 0.5° to 2.0°C higher than normal were common along the coast from Unimak Pass to Cook Inlet during the first half of 1977. During the second half of 1977 and early 1978 SST's returned to near normal although they continued mild. Water 1.0° to 2.4°C cooler than normal occurred off Prince William Sound and Cook Inlet during October 1977 to February 1978 but warmed to above normal in March 1978.

Generally both winters (1976-77 and 1977-78) were unusually warm. The mild winters and related high rainfalls have resulted in good survival of juvenile salmon as indicated by studies of preemergent fry. The warm conditions may advance the herring spawning by 1 or more weeks. Like the southeastern Bering Sea to the north across the Alaska Peninsula, the mild

[5]Otto, R. S., J. E. Reeves, and J. Burns. 1977. King and Tanner crab research in the eastern Bering Sea, 1977. Unpubl. manuscr. Northwest and Alaska Fisheries Center, NMFS, NOAA, Seattle, WA 98112.

[6]Favorite, F., T. Laevastu, and R. R. Straty. 1977. Oceanography of the northeastern Pacific Ocean and Bering Sea, and relations to various living marine resources. Processed report, 280 p. Northwest and Alaska Fisheries Center, NMFS, NOAA, Seattle, WA 98112.

[7]Seifert, R., and D. Kane. 1977. Effects of seasonability and variability of stream flow on nearshore coastal areas. Unpubl. manuscr. Inst. Water Resour., Univ. Alaska, Fairbanks, AK 99701.

[8]Averages of SST reports were made by 1° squares of latitude and longitude from observations made by passing ships and received by Fleet Numerical Weather Central. Maps of the original data are on file at Pacific Environmental Group, but for brevity only plots of SST by distance along the coast are included in this report. The long term mean values of SST are means for the period 1948-67 of SST observations in Tape Data Family-11, National Climatic Center, Environmental Data Service, NOAA, Asheville, NC 28801.

conditions which had begun in mid-1976 broke a 6-year run of below normal temperatures. This cold period was particularly serious in the Kodiak Island region where air temperature anomalies had been negative during 56 of the 69 months from August 1970 to April 1976 (anomalies were zero or positive in 11 months and data were missing in 2 months). Effects of cold weather had been severe on both salmon and pink shrimp in the Kodiak area.[9]

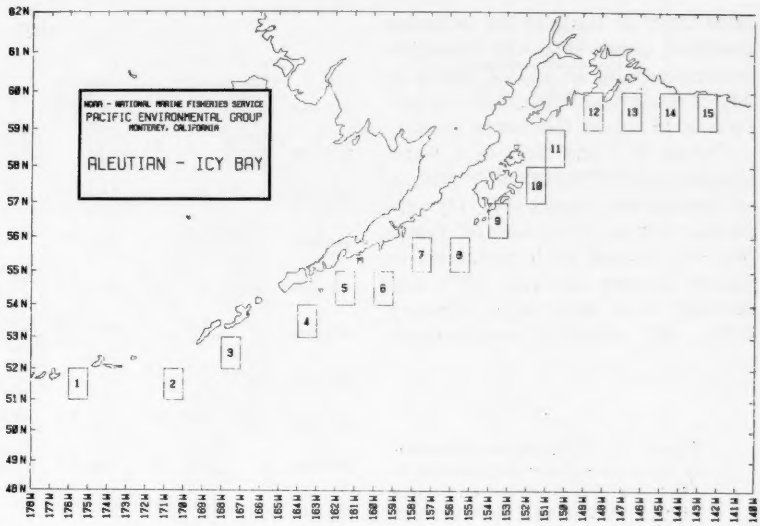
Runoff

Major rivers in this area and their annual mean discharge (100,000 meters per second) are: the Copper (2.4), Susitna (1.0), and Knik (0.7). Although a qualitative assessment of runoff indicates near normal conditions in 1977, total precipitation in Prince William Sound appeared to be below normal. Light snow pack occurred in 1978 and may result in low stream flows during the early salmon spawning season.

Salinity

Information on the distribution of surface salinity in Gulf of Alaska coastal waters during summer 1977 is available from a joint U.S.-Poland fishery oceanography survey conducted by the *Profesor Siedlecki* (Fig. 12). Immediately evident is the extensive dilution in the area of the Copper River. Another striking feature is the advection of water of less than 32‰ salinity over the continental slope at the head of the Gulf, well seaward of the inshore dilution caused by runoff from the Copper River. This apparent bifurcation of northwestward coastal flow, which has not been detected or reported before, may possibly influence the transport of ichthyoplankton, particularly halibut larvae, as well as the seaward migration path of salmon smolts from southeastern Alaska, British Columbia, Washington, and Oregon areas.

[9]Jerry McCrary, Regional Research Supervisor, Alaska Department of Fish and Game, Kodiak, AK 99615, pers. commun.



	D	J	F	M	A	M	J	J	A	S	O	N	D
1 51N 175W	4.7 (8)	4.8 (10)	3.9 (12)	3.8 (12)	4.1 (10)	5.0 (14)	6.3 (16)	7.9 (15)	9.5 (15)	9.9 (10)	7.8 (13)	6.1 (10)	4.7 (8)
2 51N 170W	4.8 (12)	4.4 (10)	3.6 (12)	3.5 (9)	4.3 (12)	5.0 (15)	6.6 (14)	8.9 (16)	10.7 (12)	10.4 (12)	8.5 (13)	6.4 (11)	4.8 (12)
3 52N 167W	5.1 (11)	4.5 (11)	4.1 (12)	4.1 (9)	4.2 (11)	5.2 (14)	6.8 (10)	9.3 (13)	11.1 (16)	10.4 (14)	8.4 (12)	6.4 (12)	5.1 (11)
4 53N 163W	5.2 (11)	4.7 (2)	3.4 (6)	3.3 (6)	4.1 (10)	5.0 (8)	7.4 (12)	9.9 (12)	11.3 (10)	10.9 (6)	8.7 (6)	6.7 (8)	5.2 (11)
5 54N 161W	5.3 (6)	4.7 (6)	4.2 (7)	3.3 (7)	4.2 (10)	5.9 (9)	7.7 (9)	9.7 (14)	11.2 (13)	10.5 (9)	8.6 (7)	7.0 (7)	5.3 (6)
6 54N 159W	4.9 (7)	4.0 (7)	4.1 (7)	4.2 (9)	3.8 (7)	5.3 (9)	8.1 (9)	10.1 (13)	11.6 (12)	11.1 (9)	8.9 (7)	6.9 (8)	4.9 (7)
7 55N 157W	4.7 (3)	3.8 (3)	4.7 (3)	3.7 (1)	3.9 (4)	5.5 (6)	7.3 (5)	9.2 (9)	10.1 (6)	10.6 (7)	8.4 (3)		4.7 (3)
8 55N 155W	4.4 (3)	3.8 (5)	3.8 (2)	3.8 (6)	4.5 (7)	5.3 (8)	7.9 (5)	9.8 (10)	10.9 (8)	10.5 (7)	7.7 (5)	5.4 (6)	4.4 (3)
9 56N 153W	4.5 (3)	3.2 (2)	3.8 (4)	5.0 (3)	3.7 (5)	5.7 (6)	8.4 (6)	9.8 (10)	10.8 (9)	10.9 (7)	9.4 (6)	8.0 (6)	4.5 (3)
10 57N 151W	5.5 (1)	4.2 (4)	4.3 (5)	3.7 (4)	4.4 (4)	5.6 (5)	8.5 (6)	10.0 (9)	10.6 (9)	10.6 (7)	9.1 (3)	6.2 (4)	5.5 (1)
11 58N 150W	6.6 (7)	5.4 (5)	4.5 (7)	5.4 (6)	4.4 (7)	5.8 (8)	8.7 (8)	10.1 (9)	11.7 (10)	10.8 (9)	9.1 (7)	6.5 (7)	6.6 (7)
12 59N 148W	6.8 (5)	6.6 (6)	5.7 (5)	5.2 (7)	4.8 (6)	6.9 (11)	10.4 (5)	12.3 (8)	13.4 (4)	11.9 (7)	10.4 (9)	8.4 (6)	6.8 (5)
13 59N 146W	7.3 (7)	6.4 (6)	6.3 (2)	5.3 (4)	5.9 (8)	7.1 (10)	10.4 (3)	11.7 (5)	13.7 (7)	12.5 (6)	10.2 (6)	8.7 (5)	7.3 (7)
14 59N 144W	7.9 (8)	5.9 (8)	5.6 (9)	5.5 (10)	5.5 (6)	7.5 (9)	10.9 (10)	12.9 (12)	13.9 (10)	13.0 (9)	10.9 (9)	8.6 (7)	7.9 (8)
15 60N 142W	8.2 (6)	5.4 (6)	5.6 (6)	6.1 (5)	5.5 (7)	6.0 (7)	10.5 (8)	12.7 (7)	13.4 (7)	12.9 (7)	11.5 (6)	8.9 (11)	8.2 (8)

Figure 10.—Location of 1° squares (upper) and 1948-67 long-term mean (lower) sea surface temperature in °C by 1° squares from Aleutian Islands to Icy Bay. Number of years of data available for each location is shown below SST value. Contour interval is 2.0°C.

Icy Bay to Strait of Juan De Fuca

The region of the northwest coast off southeastern Alaska and British Columbia is oceanographically the region where the West Wind Drift Current splits as it flows eastward toward the coast. Part flows north into the Gulf of Alaska and the remainder flows south as the California Current.

Temperature

Sea surface temperatures along the coast of southeastern Alaska and British Columbia follow somewhat the

same trend as those to the westward described earlier (Fig. 13). Minimum temperatures of 4° to 7°C occur in March or April and maximum tempertures of 13° to 16°C occur in August.

During 1977 and early 1978, water temperatures off the northern portion of southeastern Alaska (Fig. 14) were similar to those to the west off Prince William Sound with warm water during January to July 1977 and generally cool water until February 1978. Off southern southeastern

Square	1977 J	F	M	A	M	J	J	A	S	O	N	D	1978 J	F	M
1 51 N 175 W	-1.0 (2)	-.1 (3)	0.2 (5)	0.1 (5)	1.0 (10)	-.6 (5)	1.6 (5)	0.8 (2)	-.2 (10)	-.4 (5)	-1.2 (7)	0.4 (5)	1.3 (4)	-.2 (4)	0.6 (3)
2 51 N 170 W	-2.2 (2)	-.4 (4)	0.5 (1)	-1.0 (1)		1.4 (3)	0.8 (2)	1.5 (3)	0.3 (4)		0.8 (3)			0.6 (2)	0.1 (3)
3 52 N 167 W	-.7 (3)	0.3 (3)	-.9 (5)	0.6 (6)	-.1 (4)	-.4 (1)	-.4 (2)	0.6 (6)	1.1 (7)	1.7 (3)	-.1 (4)	-.4 (4)		1.1 (2)	-.6 (2)
4 53 N 163 W	1.6 (3)	1.8 (3)	-.1 (2)	-.2 (2)	0.3 (3)	0.8 (3)	2.1 (2)	-1.3 (1)	1.1 (8)	0.2 (10)	-1.3 (2)	-.2 (4)	-.9 (1)	-.1 (4)	2.4 (3)
5 54 N 161 W	-1.0 (3)	0.7 (9)	1.0 (19)	0.1 (12)	0.8 (16)	1.8 (5)	1.4 (4)	0.8 (7)	1.1 (70)	1.2 (43)	-.5 (18)	-.3 (9)	0.2 (13)	0.6 (10)	0.9 (22)
6 54 N 159 W	0.7 (9)	0.9 (6)	-.2 (46)	0.4 (14)	1.3 (11)	1.1 (8)	3.3 (7)	0.9 (7)	-.1 (7)	0.6 (22)	-.2 (27)	-.4 (15)	0.6 (13)	-.1 (14)	-.0 (21)
7 55 N 157 W	1.8 (136)	0.6 (154)	0.6 (35)	-.1 (1)		1.6 (6)	0.7 (7)	1.6 (3)	-.2 (3)	0.9 (42)		-.9 (4)	2.1 (1)	-.8 (6)	0.7 (8)
8 55 N 155 W	1.4 (2)	1.3 (8)	0.7 (11)	-.1 (4)	0.9 (3)	1.9 (3)	2.0 (7)	0.2 (1)	0.9 (6)	1.2 (12)	0.8 (7)	1.0 (6)	-.0 (5)	0.7 (47)	1.7 (2)
9 56 N 153 W		2.3 (2)	0.0 (6)	1.6 (4)	0.8 (4)	1.8 (7)	1.3 (9)	1.0 (7)	1.2 (4)	-1.2 (32)	0.9 (11)	-.2 (5)	1.7 (52)	-.1 (4)	-.1 (5)
10 57 N 151 W		1.4 (8)	0.9 (7)	1.7 (2)	-.9 (3)	-.7 (2)	1.9 (139)	0.8 (172)	0.3 (178)	-.7 (75)	-.2 (183)	-.9 (119)	0.2 (76)	0.0 (128)	0.4 (181)
11 58 N 150 W	-.1 (5)	0.4 (4)	0.4 (12)	0.8 (10)	0.4 (10)	1.1 (8)	-1.0 (4)	1.5 (8)	0.4 (9)	0.7 (18)	0.8 (11)	-1.6 (10)	1.8 (4)	-.2 (12)	0.0 (8)
12 59 N 149 W	1.5 (3)	0.2 (3)	0.4 (4)		2.5 (5)	2.9 (7)	2.8 (5)	1.9 (4)	1.4 (3)	1.8 (5)	-.5 (13)		1.7 (2)	-1.6 (3)	
13 59 N 146 W			0.2 (2)			0.7 (1)		1.2 (5)	0.9 (1)	-1.3 (1)	-1.1 (9)	-1.6 (2)	-2.1 (7)		0.8 (1)
14 59 N 144 W	0.3 (2)		0.8 (13)	1.1 (2)		1.1 (7)	1.1 (2)	0.3 (2)		-1.4 (1)	0.5 (3)	-2.4 (4)	-1.8 (3)	-1.3 (5)	1.2 (2)
15 59 N 142 W	1.4 (176)	0.6 (205)	0.1 (391)	0.7 (342)	1.0 (270)	0.5 (69)	1.0 (126)	0.1 (166)	0.7 (52)	-.3 (2)	-.2 (4)		0.7 (1)		

Figure 11.—Anomalies of monthly mean sea surface temperature in °C from 1948-67 mean and numbers of observations by 1° squares from Aleutian Islands to Icy Bay for period January 1977 to March 1978. Squares are hatched for anomalies of +1.0°C or above and shaded for anomalies of -1.0°C or below.

Figure 12.—Surface salinity in parts per thousand, July 1977. Observations made by the research vessel *Profesor Siedlecki*.

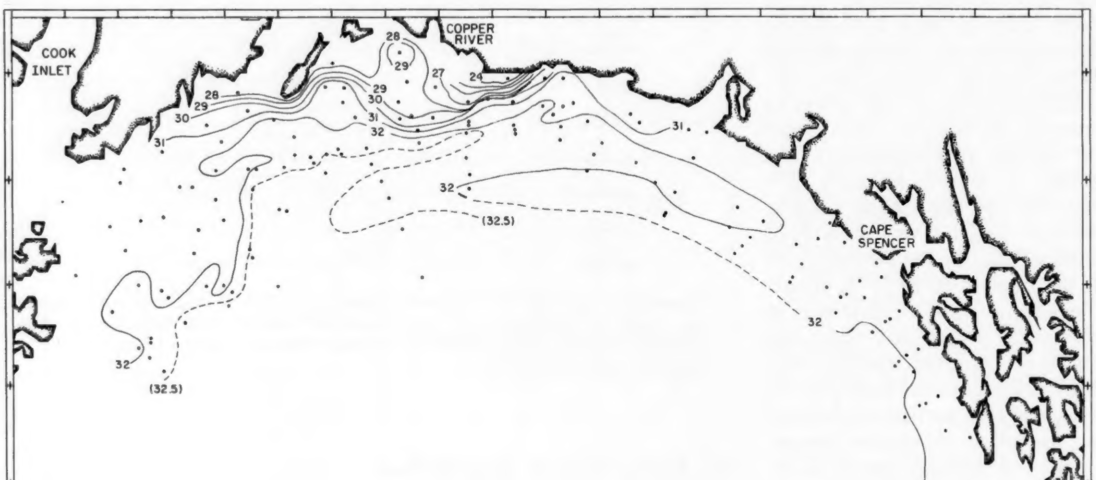


Table 1.—Representative winter sea surface temperatures (°C) at Sitka and Auke Bay, Alaska, 1976 to 1978.[1]

Area	Jan.	Feb.	Mar.	Remarks
Sitka				
1976	4.5	3.7	4.1	Cool
1977	6.4	6.1	5.7	Exceptionally warm
1978	4.2	4.6	4.8	Mild, warm
Auke Bay				
1976	2.6	2.6	2.4	Cold
1977	4.0	4.8	5.7	Exceptionally warm
1978	3.3	3.1	3.3	Mild, warm

[1]Based on data compiled by B. L. Wing, Northwest and Alaska Fisheries Center Auke Bay Laboratory, National Marine Fisheries Service, NOAA, Auke Bay, AK 99821.

Alaska and British Columbia, SST anomalies were more variable. Warmer than normal water occurred along the coast in January to March 1977 and again in March 1978. Cooler than normal water was prevalent off Vancouver Island during April to August.

Monthly mean coastal SST's are available from coastal stations at Sitka and Auke Bay, Alaska, and indicate that winter conditions were 1.5° to 3°C warmer in 1977 than 1976 and up to 0.9°C warmer in 1978 than in 1976 (Table 1).

Data on SST fluctuations along the British Columbia coast are available from four lighthouse stations in exposed locations which make daily observations.[10] Monthly means of these data show that temperatures at all four stations during the first half of 1977 were 0.5° to 1.5°C warmer than normal with greatest positive anomalies off the northern British Columbia coast. During the second half of 1977 water temperatures were near normal. In early 1978 water temperatures again became warmer than normal (0.5° to 1.0°C above normal) with greatest positive anomalies off central British Columbia.

Scattered subsurface temperature measurements by expendable bathythermographs taken during the latter

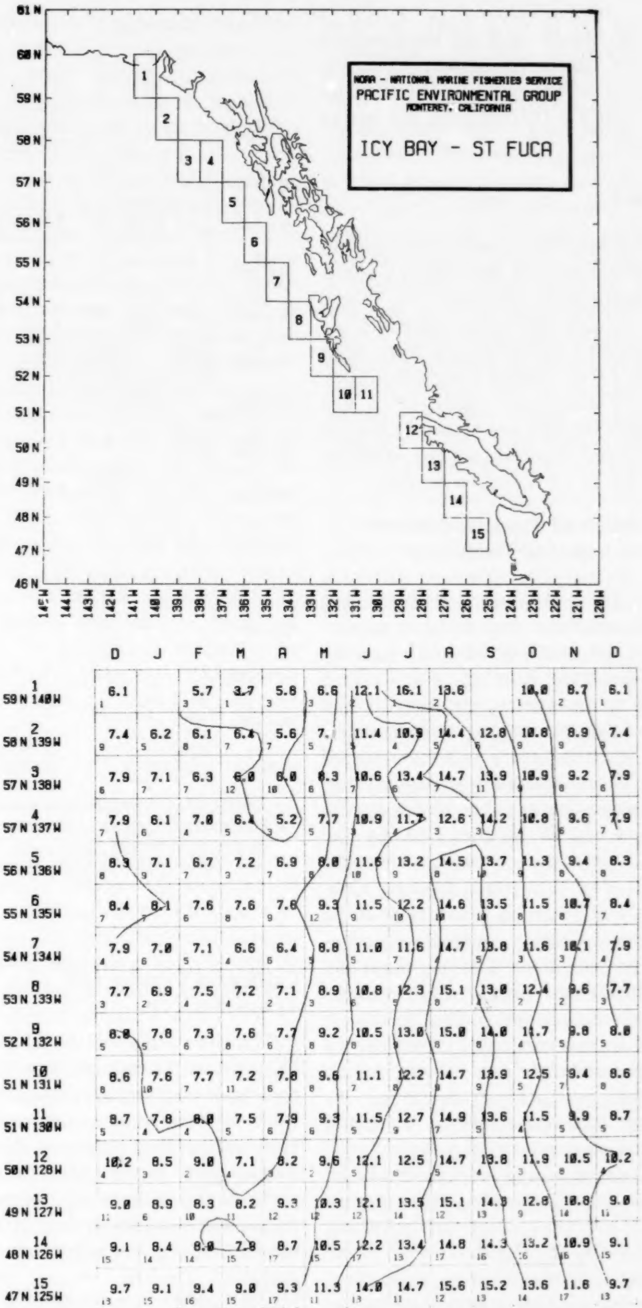


Figure 13.—Location of 1° squares (upper) and 1948-67 long-term mean (lower) sea surface temperature in °C by 1° squares from Icy Bay to Strait of Juan de Fuca. Number of years of data available for each location shown below SST value. Contour interval is 2.0°C.

[10]Monthly means of daily surface temperature and salinity observations at Langara Island, Cape St. James, Kains Island, and Amphitrite Point were kindly furnished by L. F. Giovando, Pacific Environmental Institute, Environment Canada, West Vancouver, B.C. V7V 1N6.

part of March 1978 off the southern coast of Vancouver Island indicate the presence of anomalously warm water (9.5°-10°C) throughout the water column.[11]

Salinity

Measurements of surface salinity are also made daily at the British Columbia lighthouses (footnote 10). These data indicate that water salinities off the British Columbia coast were often 0.3 to 1.0‰ above normal during 1977. Data from early 1978 are available for only one station (Langara Island) and they indicate that salinities were 0.5 to 1.0‰ below normal.

Strait of Juan De Fuca to Gulf of California

Off the west coast of the United States, relatively cool and low salinity waters are transported southward by the California Current. The Current contains meandering streams of flow and eddies but in long term averages the Current appears as a slow, broad flow. These waters are separated from the warmer, more saline North Pacific Central waters to the west by the Transition Zone—a region of ocean fronts. The northward flowing California Undercurrent lies inshore of the California Current, immediately adjacent to the coast and is seasonally variable. From Oregon southward to Baja California, prevailing northwest winds in summer cause upwelling of deeper, nutrient rich waters which support biological productivity. Ingraham and Love (1978) presented detailed observations of water temperature, salinity, and concentration of dissolved oxygen made in the summer of 1977 over the continental shelf along the coast by the Polish research vessel *Profesor Seidlecki*. The data show many details of the spatial distribution of properties but, unfortunately, comparable data are not available for other years.

	1977 J	F	M	A	M	J	J	A	S	O	N	D	1978 J	F	M
1 59 N 140 W			0.6 (14)	2.1 (2)	2.4 (1)	1.0 (1)						2.9 (1)			
2 58 N 139 W	0.8 (3)		0.2 (4)			1.4 (8)		-1.4 (1)			-.2 (5)		-.5 (7)		
3 57 N 138 W	-.3 (3)	1.7 (2)	0.3 (2)	0.7 (1)	0.0 (1)		-.1 (3)	-1.7 (1)	-.9 (3)	2.1 (2)	-.3 (1)		-1.0 (1)	-1.3 (1)	1.8 (1)
4 57 N 137 W	0.5 (5)					0.9 (2)		2.2 (1)		-.8 (1)		-2.3 (1)	-.2 (3)		
5 56 N 136 W	-.1 (3)	1.2 (1)	0.0 (1)	0.4 (1)	-.2 (1)	-.6 (1)	-1.1 (4)	-1.6 (3)	-1.7 (2)		-1.8 (3)	-2.2 (1)		-.5 (2)	
6 55 N 135 W	-1.8 (1)		-1.4 (2)	-2.6 (2)		-.5 (3)	-.3 (3)	-1.6 (1)	-.1 (2)		-2.7 (1)		-.9 (1)	-.5 (2)	
7 54 N 134 W	0.4 (3)	1.8 (2)	1.2 (1)			-.9 (2)	0.9 (1)		0.4 (2)				1.9 (1)	0.1 (4)	-.2 (3)
8 53 N 133 W	1.1 (1)		0.8 (2)	0.2 (7)	-.7 (1)	0.8 (3)	1.5 (1)	-2.4 (4)	2.2 (8)	0.6 (3)	-.2 (2)	-.2 (2)	2.1 (1)	-.3 (3)	-.7 (3)
9 52 N 132 W	0.5 (4)	0.4 (4)	-1.1 (3)	0.3 (7)	-.8 (8)	1.7 (1)	-1.3 (1)	-.2 (3)	0.3 (9)	0.5 (5)	1.3 (2)	-.4 (7)	-1.0 (6)	-.4 (12)	-.1 (4)
10 51 N 131 W	0.6 (7)	1.5 (8)	-.3 (8)	-.1 (7)	-.7 (8)	-.4 (5)	-.8 (3)	-.4 (10)	0.6 (3)	-.4 (9)	-.4 (15)	-1.1 (5)	0.9 (3)	-1.0 (2)	1.0 (11)
11 51 N 130 W	-.9 (6)	0.3 (1)	1.0 (4)	-1.7 (5)	-.1 (15)	-.0 (7)	0.5 (8)	0.0 (5)	0.6 (10)	0.4 (11)	0.1 (7)	-.6 (8)	1.0 (3)	0.8 (11)	1.7 (3)
12 50 N 128 W	-.0 (6)	0.5 (3)	1.2 (15)	-.8 (14)	0.0 (9)	-1.4 (7)	-.3 (3)	-1.2 (3)	1.1 (6)	0.2 (6)	-.6 (4)	-2.8 (4)	0.2 (6)	-.8 (7)	1.8 (5)
13 49 N 127 W	-.6 (5)	-.2 (11)	-.2 (11)	-.8 (21)	0.4 (18)	-.7 (14)	-.8 (5)	-.7 (9)	-1.5 (15)	-1.0 (10)	0.2 (11)	-1.1 (10)	-.1 (13)	0.3 (11)	1.0 (15)
14 48 N 126 W	1.1 (9)	2.4 (3)	0.2 (10)	-.3 (8)	-.1 (27)	-.7 (10)	-.1 (8)	-1.8 (5)	-1.8 (49)	-.8 (12)	-.4 (9)	0.1 (4)	1.1 (6)	-.2 (4)	0.8 (18)
15 47 N 125 W	-2.0 (5)	1.3 (9)	0.7 (13)	-.1 (5)	1.5 (7)	-2.4 (9)	1.0 (4)	-.6 (6)	-.0 (3)	0.2 (11)	-.5 (2)		-1.4 (3)	0.1 (10)	0.4 (5)

Figure 14.—Anomalies of monthly mean sea surface temperature in °C from 1948-67 mean and numbers of observations by 1° squares from Icy Bay to Strait of Juan de Fuca for period January 1977 to March 1978. Squares are hatched for anomalies of +1°C or above and shaded for anomalies of -1°C or below.

California Current and Transition Zone

The structure of the California Current and Transition Zone[12] regions has been monitored routinely since 1966 by merchant ships operating between San Francisco and Honolulu. These ships make observations of surface and subsurface temperature and surface salinity at about 120-km intervals along the track on a twice monthly schedule. Along the ship transit lane the surface water temperatures and salinities had been near normal during the winter of 1975-76 (Saur, 1978). During the winter of 1976-77 the salinities were 0.2 to 0.5‰ lower than the previous winter between long. 129° and 146°W and surface temperatures were similar to those of the previous winter (Saur and McLain, In press). During the winter of 1977-78 salinities in the same region were lower yet, 0.4-0.5‰ below average, while the corresponding temperatures had decreased on the order of 1.5°C. One possible explanation for these observations is that there was a significant increase in the advection of cool, low-salinity subarctic waters southward and into the California Current. Computations of Ekman transport (Fig. 4) suggest an increase in the West Wind Drift Current in both winters. Another possible cause is a significant increase in precipitation. During these winters

[11]A. J. Dodimead, Pacific Environmental Institute, Environment Canada, West Vancouver, B.C. V7V 1N6, pers. commun.

[12]Material for this section was developed by J. F. T. Saur, Scripps Institution of Oceanography, La Jolla, CA 92038.

there were large regions of increased southerly winds, indicative of storms and the transport of tropical, high humidity air northward. While both factors (increased advection and precipitation) were likely operative, there were some important differences in each year. During the winter of 1976-77 the winds with an anomalous southern component occurred west of long. 130° W (Fig. 2, lower). Excess local precipitation was then probably a principal cause of the observed low salinities as there is not the requisite time lag for advection to significantly alter the salinity. In the following winter (1977-78) the anomalous southern wind component occurred nearer the coast (east of long. 135°-140° W, Fig. 3, lower) where records of low salinity and high rainfall suggest excess precipitation. Farther offshore the decrease in temperature and salinity suggest that increased advection from more northerly sources was important.

The spring and early summer migration of albacore into the U.S. west coast fishery has been shown to be associated with the Transition Zone and with individual fronts within it (Laurs and Lynn, 1977). The Transition Zone is bounded by strong horizontal gradients of temperature and salinity, the subarctic and subtropic ocean fronts. The degree of development of these ocean fronts appears to affect the path of migration of albacore, their aggregation in offshore areas, and perhaps the timing of their movement into traditional nearshore fishing grounds.

Surveys of the oceanographic character of the fronts have been made annually in recent years. Such a survey was made in June 1977[13] in the region of the Transition Zone through which the albacore migrate shoreward. The survey found only remnants of the ocean fronts where in other years there had been clearly defined features. Drifter buoys were deployed in the region (lat. 33° N, long. 137° W) and monitored daily in subsequent months. While the drifting buoys retained their drogues, they moved in circuitous paths. The buoy tracks and the lack of frontal development suggest considerable ocean surface mixing.

The structure of the ocean fronts in the Transition Zone as observed from the merchant ships between San Francisco and Honolulu has been published monthly in *Fishing Information* (footnote 4) since 1972. In March 1977 there appeared to be a well defined subtropic front. In the following months a broad region of temperature inversions occurred without a strong subtropic front. This may be indicative of the mixing found by the June oceanographic survey. In September and October the subtropic front reappeared and was strongly developed. (The surface salinity, which is important in the identification of ocean fronts, was unfortunately not available for many of the transects.) By March 1978 a typical situation prevailed; both fronts were of average intensity.

Temperature

As was noted for the British Columbia coast, sea surface temperatures off Washington and Oregon (Fig. 15) are minimum in March and maximum in August. Off southern Oregon and northern California the normal seasonal warming in summer is depressed by upwelling of cold waters and summer mean temperatures do not reach 14° C, whereas 15°C temperatures are observed to both the north and south. Off central California seasonal heating again becomes dominant and surface temperatures reach summer maxima of over 16° C. The peaks are delayed a month or so, however, from those to the north with minima occurring in March or April and maxima in September.

During January and February 1977 SST's off the west coast (Fig. 16) were generally above normal (up to +2°C anomalies). A strong pulse of upwelling in March (Fig. 5) caused anomalous cooling and by April SST's were below normal along almost the entire stretch of coast with anomalies more negative than -1.0° C off central California. In May upwelling was weak and SST's rose anomalously. In June, upwelling increased again and temperatures were again below normal. Except for an area of warmer than normal water off northern California in August, SST's remained below normal through November while upwelling remained strong. Temperatures in December were generally above normal. During January through March 1978 water temperatures were consistently above normal (with anomalies of over +2.0° C common) along almost the entire stretch of coast in association with very weak upwelling and, in some instances, downwelling.

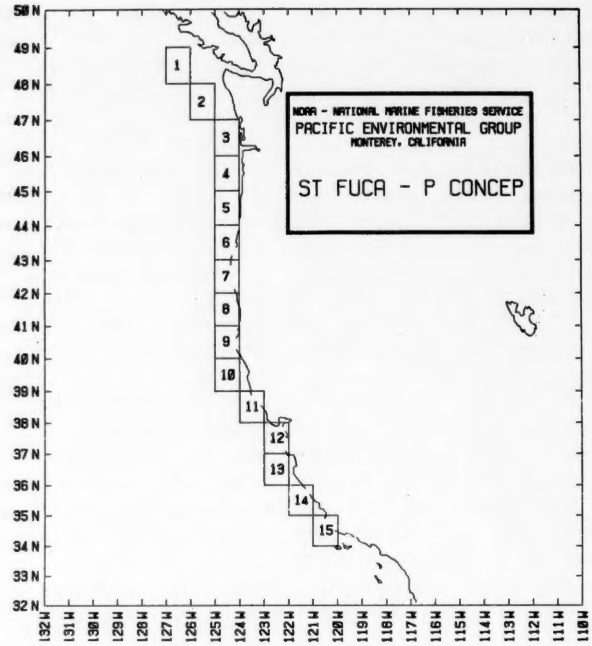
Sea surface temperatures from Point Conception southward to the Gulf of California (Fig. 17) show a regular seasonal warming and cooling cycle with minima in March to May and maxima in August or September. During January and February 1977 SST's along the coast (Fig. 18) were almost uniformly 1.5° to 2.5°C above normal as a result of calm, clear weather under the persistent high pressure system which prevailed along the coast. Due to the strong upwelling pulse in March, SST's returned to near normal values and remained near normal through July. A pulse of upwelling in August reduced SST's to below normal but conditions returned to near normal in September and October. Anomalous warming began in October and November and by December SST's were again almost uniformly above normal. Warmer than normal temperatures persisted through March 1978 when anomalies above +2°C were common off northern Baja California in March in association with weak upwelling.

Upwelling

Bakun and Parrish[14] have recomputed the indices of intensity of coastal

[13]Lynn, R. J. Unpublished cruise report, Cruise 111, RV *David Starr Jordan*, Southwest Fisheries Center, NMFS, NOAA, La Jolla, CA 92038.

[14]Reported in the Monthly Report for March 1978, Southwest Fisheries Center, NMFS, NOAA, La Jolla, CA 92038.



	D	J	F	M	A	M	J	J	A	S	O	N	D
1 48 N 126 W	9.1 15	8.4 14	8.0 14	7.8 15	8.7 17	10.5 15	12.2 17	13.4 13	14.8 17	14.3 16	13.2 16	10.9 16	9.1 15
2 47 N 125 W	9.7 13	9.1 15	9.4 16	9.0 15	9.3 17	11.3 11	14.0 13	14.7 11	15.6 12	15.2 13	13.6 14	11.6 17	9.7 13
3 46 N 124 W	10.3 9	9.7 9	9.2 14	9.0 15	10.0 14	11.9 13	13.8 14	15.0 14	15.7 14	15.4 14	13.5 13	12.0 15	10.3 9
4 45 N 124 W	10.8 12	9.9 14	9.6 13	9.5 18	10.2 16	11.8 17	13.9 16	14.8 13	15.8 17	15.3 17	13.9 14	12.0 16	10.8 12
5 44 N 124 W	11.1 17	10.2 13	9.9 16	9.7 18	10.2 17	11.2 16	13.6 16	14.0 14	14.5 15	14.6 14	14.0 17	12.1 14	11.1 17
6 43 N 124 W	11.1 16	10.6 15	10.1 14	9.8 17	10.5 18	11.5 16	13.0 16	13.1 15	13.8 12	14.0 18	13.3 13	12.1 16	11.1 16
7 42 N 124 W	11.7 17	10.5 14	10.5 15	10.5 18	10.4 17	11.4 17	11.9 16	11.8 16	12.6 14	13.3 18	13.1 17	12.6 16	11.7 17
8 41 N 124 W	11.9 17	11.0 15	10.7 16	10.6 18	10.6 17	11.3 18	12.1 18	11.9 16	12.3 16	13.0 18	12.8 16	12.2 17	11.9 17
9 40 N 124 W	12.3 17	11.1 15	10.8 16	10.8 18	10.8 17	11.8 18	11.8 18	12.0 17	12.7 14	13.2 17	13.2 17	12.6 18	12.3 17
10 39 N 124 W	12.7 19	11.5 20	11.4 18	11.1 20	10.7 20	11.6 20	12.1 20	12.6 20	12.9 20	13.7 19	13.5 19	13.3 20	12.7 19
11 38 N 123 W	12.8 19	11.6 19	11.6 19	11.4 20	11.3 20	11.6 20	12.0 20	12.6 19	13.5 20	13.7 18	14.0 20	13.5 20	12.8 19
12 37 N 122 W	12.7 19	12.2 19	12.3 18	12.2 20	12.1 18	12.7 19	13.6 20	14.2 19	14.6 20	15.8 20	15.2 19	14.0 20	12.7 19
13 36 N 122 W	13.7 19	12.8 20	12.4 19	12.3 20	12.4 20	12.7 20	13.5 20	14.3 20	14.6 20	15.6 20	15.1 19	14.3 20	13.7 19
14 35 N 121 W	13.9 20	12.9 20	12.9 20	12.7 20	12.5 20	12.5 20	13.5 20	14.3 20	14.9 20	15.6 20	15.5 20	14.8 20	13.9 20
15 34 N 120 W	14.4 19	13.6 20	13.4 19	12.9 20	12.9 19	13.2 20	14.0 20	15.5 20	16.1 17	16.6 20	16.1 20	15.4 20	14.4 19

Figure 15.—Location of 1° squares (upper) and 1948-67 long-term mean (lower) sea surface temperature in °C by 1° squares from Strait of Juan de Fuca to Point Conception. Number of years of data available for each location shown below SST value. Contour interval is 2.0°C.

upwelling, described earlier, at 6-hourly intervals for the winters of 1976-77 and 1977-78. They showed that the patterns of upwelling were very different during the two periods. Off California the relatively strong upwelling in the winter of 1976-77 was a relaxed, low-energy situation under the persistent high pressure system that prevailed over California at that time. In contrast the winter of 1977-78 was marked by intense, highly fluctuating upwelling and downwelling episodes as storms moved onto the coast. In monthly averages these episodes appeared as weak upwelling (or downwelling).

The biological effects of these two patterns of upwelling would be quite different. The slack conditions from November to February of 1976-77 should have subjected organisms to less than normal levels of onshore and offshore excursions of surface waters, to reduced turbulent mixing, and to reduced dispersion of planktonic aggregations. During 1977-78, however, strong pulses of wind caused onshore-offshore excursions which should have caused strong turbulent mixing, destroying patch structure of plankton. Smith and Lasker (1978) suggested that changes in concentrations of plankton due to upwelling changes may be an important factor in survival of larval anchovies.

Runoff

The Columbia River, whose seaward discharge is second only to the Yukon River, and the accumulated flow from the Fraser River and the Puget Sound Basin that discharges through the Strait of Juan de Fuca, are nearly equivalent. However, mixing and stirring processes in the Strait diminish the salinity differences between inshore and coastal waters, whereas marked salinity gradients occur at the edges of the Columbia River plume. Columbia River runoff data for January to September 1977 (Fig. 19) indicate a 50 percent reduction from the same period in 1976, reflecting the west coast drought. Perhaps more significant is the absence of a peak discharge in May or June

1977. During this annual, critical runoff period, flow was only a third of normal conditions and half those of 1976. The absence of this annual pulse of freshwater could have a variety of effects on salmon in the river and on coastal marine organisms.

Salinity

Lower than normal surface salinities were observed by the merchant ships in the California Current between San Francisco and Honolulu as has been mentioned. Low salinities were also observed on research cruises of the California Cooperative Oceanic Fisheries Investigations in early 1978. The cruises covered roughly the area within 450 km of the coastline from central California to Baja California. The series of surveys, in December 1977 and January, March, and April 1978, revealed an increasing and expanding salt deficit in the surface layer. The freshened waters are attributed to unusually high local precipitation which reflected the heavy rains observed at coastal stations. The excess rainfall, computed as that amount of freshwater required to produce the salinity anomaly, was approximately 0.5 to 1 m over the 5 months, December 1977—April 1978. This amount is twice the excess rainfall recorded at San Diego (0.22 m) and Santa Barbara (0.57 m) for the same period and 2-3 times the estimated annual average rainfall. The anomalously low salinities extended well into the pycnocline. The low salinity values at depth may be due to increased advection of low salinity water from the north.

	1977												1978		
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1 48N 126W	1.1 9	2.4 3	0.2 10	-.3 8	-.1 27	-.7 10	-.1 8	-1.0 5	-1.0 49	-.8 12	-.4 9	0.1 4	1.1 8	-.2 4	0.8 10
2 47N 125W	-2.0 5	1.3 9	0.7 13	-.1 5	1.5 7	-2.4 9	1.0 4	-.6 8	-.0 3	0.2 11	-.5 2		-1.4 3	0.1 10	0.4 5
3 46N 124W	-.9 190	0.1 173	0.2 223	-.1 189	-.4 21	-.6 12	-2.0 119	-2.0 183	-.8 246	0.9 261	0.2 241	-.3 245	0.2 220	0.6 241	0.6 253
4 45N 124W	1.1 1	0.2 7	0.7 15	-.2 5	0.2 9	-.6 131	0.0 36	-.3 28	-1.0 98	-.5 31	-.9 8	1.0 6	1.2 6	0.9 9	1.4 5
5 44N 124W	-.2 6	1.3 4	0.6 6	0.6 5	1.7 13	-1.1 208	-.7 77	-.6 346	-.4 395	0.2 130	-1.0 6	-.5 4	1.1 6	1.0 12	2.5 7
6 43N 124W	0.0 6	0.6 6	0.1 9	-.4 9	0.8 21	-.6 79	0.1 52	-.9 383	0.2 400	0.8 146	-.6 7		1.3 4	1.5 15	1.9 8
7 42N 124W	1.4 8	1.4 7	0.1 11	-.2 7	1.6 17	-.1 36	0.8 159	0.1 125	-.2 30	-.1 14	0.4 9	0.4 4	1.5 3	2.0 8	1.2 6
8 41N 124W	-.2 5	1.6 10	0.7 15	-.5 14	0.8 17	0.4 26	0.5 268	1.2 45	0.6 30	-.4 6	-.1 11	-.7 7	0.5 4	0.7 11	2.0 7
9 40N 124W	0.8 11	0.5 8	0.2 15	-.5 15	0.2 16	-.7 14	0.7 123	1.1 14	-.3 19	0.2 9	-.0 7	1.1 2	1.0 6	2.0 13	1.5 7
10 39N 124W	0.9 12	0.7 21	0.1 18	-.6 14	-.2 24	-1.1 15	0.1 11	1.3 15	-.4 25	-.4 11	-.8 12	0.4 6	0.7 11	0.8 20	1.6 10
11 38N 123W	0.7 10	1.1 12	0.6 10	-.9 11	1.5 14	-1.7 11	-1.9 11	-.7 8	-.2 11	-.4 8	-.4 7	0.4 10	1.3 6	1.3 9	1.5 8
12 37N 122W	1.4 6	1.4 8	-.1 18	-1.8 1	-.3 8	-.6 8	-2.0 6	0.7 5	-1.4 6		0.8 5	1.0 9	2.1 4	1.2 12	0.2 4
13 36N 122W	1.1 6	1.0 11	-.6 20	-1.4 12	0.7 14	-.5 8	-1.9 6	-.2 7	0.1 16	-.2 17	-1.1 10	-.9 10	0.8 12	1.7 25	0.9 12
14 35N 121W	1.3 12	1.0 13	-.5 21	-1.4 12	0.1 15	-1.3 10	0.1 19	-.4 7	0.6 12	0.1 12	-1.1 11	1.0 8	0.8 12	1.0 17	1.5 17
15 34N 120W	2.0 8	1.7 15	-.1 13	-1.0 14	-.6 11	-1.5 4	0.8 12	-2.5 7	0.9 11	0.1 13	-.8 7	0.5 7	2.7 3	0.8 10	1.5 15

Figure 16.—Anomalies of monthly mean sea surface temperature in °C from 1948-67 mean and numbers of observations by 1° squares from Strait of Juan de Fuca to Point Conception for the period January 1977 to March 1978. Squares are hatched for anomalies of °C or above and shaded for anomalies of -1°C or below.

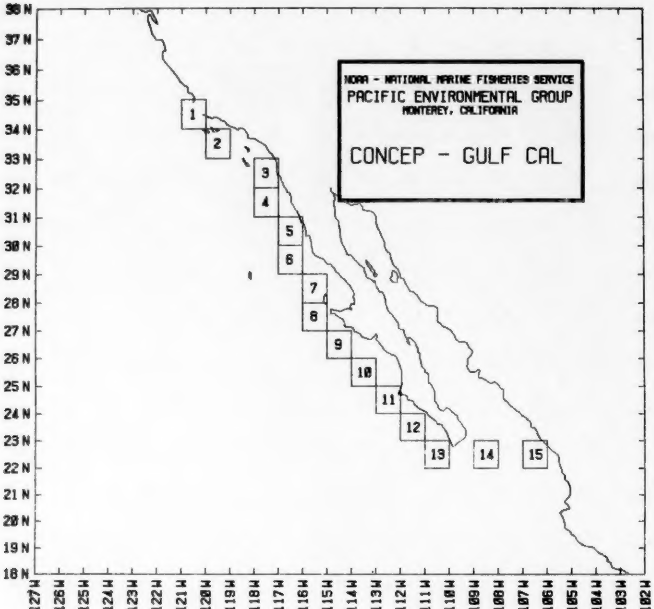
Eastern Tropical Pacific Conditions

Oceanographic conditions in the eastern tropical Pacific (ETP) are influenced by the Equatorial current systems and their variations.[15] The trade winds of the equatorial regions drive the westward flowing North and South Equatorial Currents.

The North and South Equatorial Countercurrents flow eastward. Variations in these currents occur and major changes, known as El Niño events, transport unusually large amounts of warm, saline waters towards the coast. Such events are related to fluctuations in the strength and position of the trade winds over large areas of the tropical Pacific. Quinn (1976, 1978, in press) has described relations of El Niño conditions in the ETP to the Southern Oscillation—a variation of atmospheric pressure across the tropical Pacific Ocean. Upwelling occurs off the west coasts of Peru and Ecuador and along a broad band westward along the Equator as a result of divergence caused by the trade winds. Upwelling is strongest during August and September.

Variations in oceanographic conditions in the ETP affect the fishery resources of the area in various ways. A major El Niño event occurred in 1972 and was followed by a serious decline in production of anchoveta off Peru. The exact mechanism of the decline is still in question but it no doubt involved a combination of heavy fishing pressure and environmental change. Tunas are mobile, highly migratory animals and are related to their environment in complex ways. Changes in the distribution and availability of tunas are related to variations in SST, thermocline depth, and other oceanographic conditions while variations in skipjack tuna

[15]Much of the material of this section was prepared by Forrest Miller, Inter-American Tropical Tuna Commission, La Jolla, CA 92037. It is based on material developed for *Fishing Information* and the reader is referred to that publication for charts of monthly sea surface temperature (SST) and anomaly of SST from a long-term mean.



	D	J	F	M	A	M	J	J	A	S	O	N	D
1 34 N 120 W	14.4 19	13.6 20	13.4 19	12.9 20	12.9 19	13.2 20	14.0 20	15.5 20	16.1 17	16.6 20	16.1 20	15.4 20	14.4 19
2 33 N 119 W	15.8 19	14.4 19	14.3 20	14.3 20	14.4 20	15.0 20	15.9 20	17.6 20	18.6 20	18.7 20	18.3 20	16.6 20	15.8 19
3 32 N 117 W	16.4 20	14.9 20	14.7 20	15.0 20	15.7 20	16.2 20	17.2 20	19.0 20	20.0 20	19.8 20	19.1 20	17.6 20	16.4 20
4 31 N 117 W	16.7 20	15.6 20	15.1 20	15.1 20	15.7 20	16.4 20	17.1 20	18.5 20	20.0 20	20.0 20	19.2 20	17.9 20	16.7 20
5 30 N 116 W	17.1 19	15.9 19	15.6 20	15.4 20	15.8 20	16.2 20	16.8 20	18.5 20	19.9 20	20.2 20	19.4 20	18.2 20	17.1 19
6 29 N 116 W	17.5 20	16.2 20	15.9 20	15.7 20	15.9 20	16.4 20	17.1 20	18.6 20	20.1 20	20.5 20	19.9 20	18.7 20	17.5 20
7 28 N 115 W	18.2 19	17.0 19	16.2 19	15.8 20	16.0 20	16.2 20	16.9 20	18.7 20	20.3 19	21.0 20	20.5 19	19.4 20	18.2 19
8 27 N 115 W	18.8 20	17.4 20	16.6 20	16.1 20	16.1 20	16.4 20	17.0 20	19.1 20	20.8 20	21.7 20	21.3 20	20.0 20	18.8 20
9 26 N 114 W	20.1 20	18.5 20	17.7 20	16.9 20	16.6 20	16.8 20	17.4 20	19.8 20	21.9 20	23.0 20	22.7 20	21.2 20	20.1 20
10 25 N 113 W	21.2 20	19.5 20	18.6 20	17.6 20	17.2 20	17.2 20	18.0 20	20.9 20	23.3 20	24.6 20	24.1 20	22.7 20	21.2 20
11 24 N 112 W	22.5 20	20.5 20	19.3 20	18.2 20	17.8 20	17.5 20	18.2 20	22.0 20	24.9 20	26.2 20	25.6 20	23.9 20	22.5 20
12 23 N 111 W	23.6 20	21.6 20	20.3 20	19.3 20	18.8 20	18.6 20	19.4 20	23.4 20	26.6 20	27.5 20	26.7 20	25.1 20	23.6 20
13 22 N 110 W	24.4 20	22.5 20	21.4 20	20.8 20	20.6 20	20.6 20	21.9 20	25.2 20	27.9 20	28.3 20	27.5 20	26.2 20	24.4 20
14 22 N 108 W	25.4 14	23.1 10	22.5 12	22.6 13	22.5 14	24.0 14	25.0 18	27.1 17	28.9 15	29.0 11	29.0 13	27.3 14	25.4 14
15 22 N 106 W	26.1 1	24.1 3	24.0 1	22.9 6	24.0 4	27.1 4	27.7 2	30.1 6	29.7 5	29.9 4	27.9 1	28.2 3	26.1 1

Figure 17.—Location of 1° squares (upper) and 1948-67 long-term mean (lower) sea surface temperature in °C by 1° squares from Point Conception to Gulf of California. Number of years of data available for each location shown below SST value. Contour interval is 2.0°C.

abundance have been correlated with the Southern Oscillation.

Sea Surface Temperature

Fluctuations of oceanographic conditions in the ETP are commonly monitored from patterns of SST. Such patterns can be characterized as complex patterns of ocean fronts bordering on large warm and cool water areas. Fairly regular seasonal changes occur in the locations and intensities of these frontal boundaries and associated SST patterns. The seasonal pattern is modified in El Niño years when SST's are unusually high over most of the ETP and ocean fronts along the Equator are weak. Frequently, during 1 or more years preceding an El Niño, SST's are abnormally low over large areas of the tropics, especially along the Equator as a result of strong trade winds and strong equatorial upwelling.

A moderately intense El Niño had occurred in 1976 (Quinn, in press) with associated positive SST anomalies reaching a maximum in December 1976. During January to March 1977 (Fig. 20), SST's remained above normal over most of the ETP. As was seen in Figure 18, SST's along the coast of Baja California were more than 1°C above normal. Along the southwest coast of Central America and over most of the ETP north of lat. 5°N, SST's were within 0.5°C of normal. Along the Equator east of long. 150°W and off Peru, there were several areas where SST's were more than 1°C above normal from the warming during the 1976 El Niño although these areas diminished rapidly in size during January. The Gulfs of Tehuantepec and Panama and waters off the south coast of Peru (south of lat. 15°S) all experienced SST's which were more than 1°C below normal during the first quarter due to strong wind mixing.

During April to June a distinct shift from warm to cool conditions took place over most of the coastal areas off the west coasts of Mexico (Fig. 18) and also off Central and South America with SST's reaching as much as 1°C below normal off Ecuador. Along the Equator from lat. 5°N to 5°S upwelling reduced SST's to 0.5° to 1°C below

normal in April. During May the area of negative SST anomalies (more than 1°C below normal) expanded westward from the Galapagos Islands-Ecuador region. This pattern of SST anomalies—below normal temperatures off Central and South America and along the Equator and near normal temperatures elsewhere in the ETP—persisted through October. Maximum negative anomalies (as much as -1.5°C below normal) due to upwelling along the Equator occurred in September. During 1977 the Southern Hemisphere subtropical high pressure system (normally centered near lat. 30°S, long. 90°W) was not in its normal position and surface pressures were frequently below normal. As a result, the southeast trade winds and upwelling were weaker than normal along the coast of South America and over the equatorial central Pacific.

During July to December, SST's in the Northern Hemisphere and west of long. 120°W warmed faster than normal and the eastern part of the ETP north of the Equator warmed more slowly than normal. Negative anomalies along the Central American coast (east of long. 100°W and north of lat. 5°N) occurred during this period and were associated with increases in tropical storm activity which increased markedly in July. A band of negative SST anomalies offshore of the coast of Central America and Mexico occurred in areas of heavy wind mixing in the paths of tropical storms which developed from July to October 1977.

Apart from seasonal changes the SST anomalies during October to December did not markedly change from earlier conditions. Tropical storm activity in the ETP from Costa Rica to Baja California continued through October leaving a broad zone of deeply mixed tropical water and scattered areas with negative anomalies (greater than 1°C below normal) where storms intensified most often. West of long. 120°W and south of lat. 20°N SST's were more than 1°C above normal due to below normal cloud cover and light trade winds. By November the areas of large positive anomalies were reduced

	1977 J	F	M	A	M	J	J	A	S	O	N	D	1978 J	F	M
1 34N 120W	2.0 (9)	1.7 (15)	-.1 (13)	-1.0 (11)	-.6 (11)	-1.5 (4)	0.8 (12)	-2.5 (7)	0.9 (11)	0.1 (13)	-.8 (7)	0.5 (7)	2.7 (3)	0.8 (10)	1.5 (15)
2 33N 119W	0.3 (4)	1.2 (4)	0.3 (17)	-.6 (7)	0.5 (4)	-.5 (7)	-1.0 (7)	-.3 (13)	0.3 (4)	-.2 (3)	0.6 (7)	-.3 (8)	1.2 (3)	1.7 (5)	1.3 (11)
3 32N 117W	2.2 (14)	2.3 (4)	1.4 (12)	0.7 (28)	0.2 (20)	0.2 (51)	0.3 (15)	-.1 (12)	0.1 (13)	1.1 (18)	1.0 (27)	1.0 (19)	1.7 (5)	0.4 (12)	2.5 (19)
4 31N 117W	1.3 (15)	1.9 (9)	1.1 (7)	0.3 (23)	0.4 (10)	0.2 (8)	0.1 (4)	0.2 (14)	0.5 (18)	1.4 (12)	2.2 (9)	1.2 (18)	0.8 (8)	1.5 (13)	2.4 (8)
5 30N 116W	2.2 (6)	2.4 (6)	-.0 (17)	-.5 (26)	-.2 (11)	0.2 (9)	0.7 (2)	-.1 (13)	-.1 (23)	-.1 (23)	1.0 (12)	1.5 (12)	1.6 (6)	1.2 (9)	2.2 (15)
6 29N 116W	2.1 (28)	0.6 (15)	1.1 (28)	0.5 (27)	0.5 (14)	-.5 (13)	1.5 (7)	-.2 (6)	0.6 (22)	-.1 (15)	0.1 (12)	2.2 (21)	2.3 (14)	2.1 (20)	2.3 (18)
7 28N 115W	2.4 (7)	2.3 (7)	1.4 (12)	0.1 (15)	0.4 (7)	0.0 (16)	0.8 (3)	-.3 (7)	0.8 (10)	0.3 (21)	0.7 (13)	2.2 (15)	1.9 (15)	1.7 (11)	2.3 (11)
8 27N 115W	2.0 (13)	1.5 (14)	1.8 (23)	0.1 (24)	0.8 (20)	0.9 (16)	0.3 (4)	-.5 (11)	0.7 (18)	-.0 (26)	1.3 (28)	1.2 (18)	1.3 (18)	1.9 (10)	2.3 (17)
9 26N 114W	1.5 (20)	1.5 (10)	1.1 (16)	0.4 (22)	0.3 (20)	0.4 (29)	0.5 (16)	-.5 (15)	0.8 (25)	1.0 (15)	1.3 (22)	1.7 (25)	1.8 (28)	0.7 (13)	1.9 (16)
10 25N 113W	1.0 (12)	1.5 (13)	0.8 (19)	0.3 (23)	0.8 (20)	0.4 (22)	0.3 (9)	0.1 (19)	-.2 (18)	0.5 (18)	0.2 (14)	1.1 (21)	1.3 (14)	1.1 (24)	1.5 (18)
11 24N 112W	1.0 (14)	0.8 (11)	1.5 (13)	1.0 (21)	0.4 (18)	0.6 (17)	-1.0 (8)	-.3 (9)	-.3 (12)	0.1 (21)	1.4 (21)	0.6 (13)	1.4 (14)	0.5 (10)	1.7 (12)
12 23N 111W	1.2 (17)	1.4 (14)	2.7 (17)	2.0 (23)	0.3 (8)	1.8 (18)	0.1 (13)	-.9 (12)	0.1 (23)	0.8 (16)	0.7 (18)	0.7 (12)	2.1 (12)	1.3 (14)	0.3 (10)
13 22N 110W	1.0 (10)	1.5 (7)	1.1 (19)	0.2 (19)	1.0 (7)	-.2 (14)	-.5 (8)	-1.6 (19)	-.1 (23)	0.7 (21)	0.8 (23)	1.9 (11)	2.0 (10)	1.0 (14)	0.6 (11)
14 22N 108W	1.6 (7)		1.6 (5)	1.9 (5)	0.8 (3)	-3.0 (8)		-2.2 (1)	1.3 (3)	0.4 (3)	0.6 (1)	0.6 (4)	2.4 (3)	1.5 (2)	-.6 (1)
15 22N 106W			-2.1 (1)		-1.1 (2)				1.1 (2)	2.4 (4)	0.8 (2)	1.3 (4)		0.0 (1)	

Figure 18.—Anomalies of monthly mean sea surface temperature in °C from 1948-67 mean and numbers of observations by 1° squares from Point Conception to Gulf of California for period January 1977 to March 1978. Squares are hatched for anomalies of +1°C or above and shaded for anomalies of -1°C or below.

in size. In the Southern Hemisphere SST's remained slightly above normal with scattered areas of positive anomalies greater than 1°C until the end of the year. However, by December SST's in the area west of long. 85°W from lat. 5° to 30°S, which had been above normal since May 1975, were beginning to return to normal. Along the coast of South America and along the Equator (lat. 5°N to 5°S), SST's were, on an average, slightly below normal most of the time with an occasional positive anomaly extending into the equatorial region from the trade wind zones of both hemispheres.

During January 1978 temperatures throughout the ETP were near normal with the exceptions of warmer than normal water off Baja California due to the weak upwelling there and cooler than normal water off Peru and west of

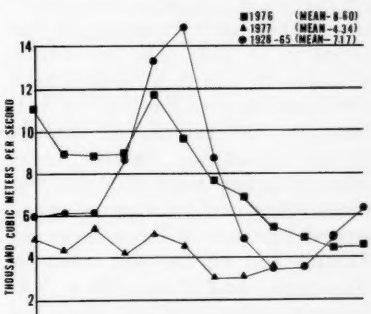


Figure 19.—Discharge of Columbia River near Astoria for 1976 and 1977 and 1928-65 long-term mean in thousands of cubic meters per second. Data from U.S. Geological Survey.

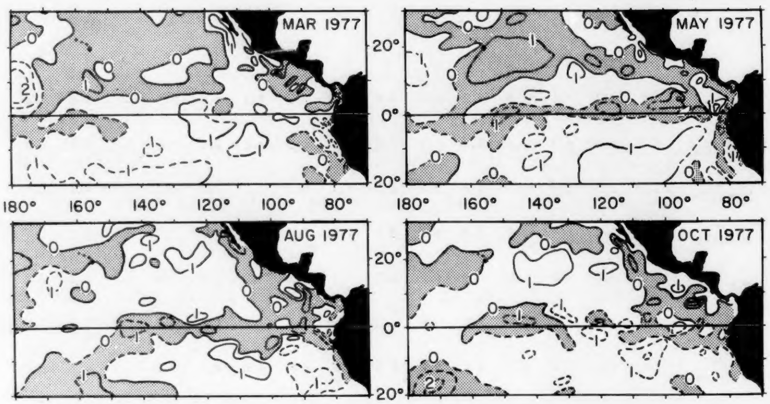


Figure 20.—Departure of sea surface temperature (in °C) from long term monthly averages in the eastern tropical Pacific Ocean for 4 months of 1977. Shaded areas are below average. (Adapted from *Fishing Information*.)

the Galapagos Islands due to strong upwelling. Below normal water temperatures continued to occur in the Gulfs of Tehuantepec and Panama due to wind mixing. This pattern continued during February and March although the cooler than normal water west of the Galapagos Islands was not present in March.

Tuna Fishing Conditions

From January through April 1977 the catches of yellowfin tuna east of long. 100°W were the lowest for that period in 18 years. The low catches were due in part to a tie-up (during April and May) of much of the U.S. tuna fleet in response to porpoise fishing regulations. Another factor affecting fishing in the ETP was high winds which prevailed all winter in and around the Gulfs of Tehuantepec and Panama and off the west coasts of Nicaragua and Costa Rica. The frequent outbreaks of high winds and rough seas kept the tuna fleet on the move in the ETP looking for suitable fishing areas. During May and June there was considerable tuna fishing activity along the southwest coast of Baja California near a strong north-south SST gradient. By May above normal SST's and related light winds and seas attracted large numbers of tuna boats to an area west of long. 110°W and south of lat. 10°N where fishing was good. However, tuna fishermen east of long. 110°W between lat. 5° and 15°N reported poor fishing from April to mid-June due to an extensive area of high SST's (29°C and greater) that persisted throughout the second quarter.

During most of the period from July to December, tuna fishing on the "Local Banks" off the west coast of Baja California was better than usual because of the above normal SST's and to the strong north-south gradient of SST south of lat. 25°N. South of Mexico and west of Cental America fishing activity was considerably reduced from July to October because of the development of frequent and intense tropical storms. Wind mixing of the surface layers in the path of storms made the location of fish and purse seining difficult from lat. 10°N to 10°S and along the coast to long. 115°W. During the last half of 1977 many tuna boats moved south to an area south of lat. 5°N between long. 120° and 100°W where fishing weather was better than farther north and SST's were in the range 25° to 28°C. This fishing area was probably south of the north Equatorial Counter Current and north of the equatorial ocean front where forage may aggregate and attract large schools of tuna.

Acknowledgments

Data for this report were provided by Fleet Numerical Weather Central, Monterey, Calif. Andrew Bakun made the computations of Ekman transport and upwelling index. Jim Renner contributed plots of atmospheric pressure and winds. Jim Ingraham compiled material on conditions in the Gulf of Alaska as did J.F.T. Saur for the California Current. Forrest Miller contributed material on oceanographic and fishery conditions in the eastern tropical Pacific. Elizabeth Haynes, R. Michael Laurs, and Robert Pedrick reviewed the manuscript and suggested improvements.

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west coast, as monitored by ships of opportunity - 1975. *In* J. R. Goulet, Jr. and E. D. Haynes (editors), Ocean variability: Effects on U.S. marine fishery resources - 1975, p. 151-168. U.S. Dep. Commer., NOAA Tech. Rep. NMFS Circ. 416.

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Appendix I

Principal Sources of Data and Information Used:

Atlantic Environmental Group, National Marine Fisheries Service, NOAA, Narragansett, RI 02882. Surface and subsurface temperature data from monthly XBT transects off New York and southern New England. Unpublished reports by staff oceanographers.

Environment Canada, Pacific Environmental Institute, West Vancouver, B.C. V7V 1N6. Monthly means of daily surface temperature and salinity observations from Canadian lighthouse stations. Scattered subsurface temperature observations in Canadian waters.

Fishery Engineering Laboratory, National Marine Fisheries Service, NOAA, Bay St. Louis, MS 39529. Unpublished data on Mississippi River flow and positions of the East Gulf loop current.

National Climatic Center, Environmental Data Service, NOAA, Asheville, NC 28801. Local climatological data: monthly summaries of daily and 3-hourly observations at selected weather stations.

National Environmental Satellite Service, NOAA, Washington, DC 20233. Weekly satellite-observed Gulf Stream analysis charts. Miami SSFS Analysis charts produced weekly.

Northeast Fisheries Center, National Marine Fisheries Service, NOAA, Woods Hole, MA 02543. Surface and subsurface temperature data and surface salinity data from monthly transects across the Gulf of Maine. Unpublished reports by staff scientists.

Pacific Environmental Group, National Marine Fisheries Serivce, NOAA, Monterey, CA 93940. Sea surface temperature anomaly charts: monthly by 1° square. Computer processed transects of expendable bathythermograph and salinity observations from ships of opportunity between San Francisco, Calif., and Honolulu, Hawaii. Space-time plots of sea surface temperature anomalies for selected 1° squares along the Atlantic coast. Computations of surface layer (Ekman) transport and listouts of data: monthly on alter nate 5° or every 3° grid.

U.S. Army Corps of Engineers Regional Office, New Orleans, La. Mississippi River discharge data.

Appendix II

Publications scanned for environmental or fisheries information:

Mariners Weather Log, (bi-monthly), Environmental Data Service, NOAA, Washington, DC 20235.

Monthly Weather Review, American Meteorological Society, Boston, MA 02108.

National Fisherman, (monthly newspaper), Camden, ME 04843.

Fishing Information, (monthly), Southwest Fisheries Center, National Marine Fisheries Service, NOAA, La Jolla, CA 92038.

U.S. Geological Survey Periodic summaries of streamflow data in various regions in the Atlantic and Gulf coastal areas, issued on varying time schedules by Regional Offices (advance release of data may be arranged by personal communication).

U.S. Naval Oceanographic Office, Washington, D.C. Experimental ocean frontal analysis charts produced weekly from satellite infrared imagery and expendable bathythermograph observations.

Virginia Institute of Marine Sciences, Gloucester Point, Va. Press releases regarding fisheries status.

NOAA Ocean Climate Study Begins in Equatorial Pacific

The National Oceanic and Atmospheric Administration (NOAA) has begun the first major study of how Pacific Ocean waters reflect changes in global climate. The Equatorial Pacific Ocean Climate Studies (EPOCS) seeks to determine the driving forces behind large variations in sea surface temperature, and how these variations are linked to climatic changes, according to Richard A. Frank, Administrator of NOAA.

The study is a highly focused, multiyear program of experimentation and research, the Commerce Department agency official said, which it is hoped will provide useful new insights into how the "climate machine" works. At the heart of the climate machine—and the research—is the relationship between the ocean and atmosphere; a kind of geophysical marriage of opposites. The atmosphere is the flambouyant, active partner, with a short memory. The ocean is the stable partner, long of memory, given to hoarding energy which is squandered by the atmosphere.

One of the more energetic and variable parts of the climate machine is the equatorial Pacific, a huge and influential source of stored heat, and an enormous engine for the redistribution and release of that heat into the tropical atmosphere. This energetic part emits tantalizingly strong climatic signals, according to Joseph O. Fletcher, EPOCS director and deputy director of NOAA's Environmental Research Laboratories in Boulder, Colo.

"It seems clear that, on a year-to-year basis, the spatial distribution of heat released into the atmosphere appears to be associated with large sea-surface temperature anomalies in the eastern tropical Pacific", he explained. "These anomalies—that is, warmer or cooler deviations from the long-term average sea-surface temperature—are quite large, amounting to several degrees Celsius over thousands of miles and perhaps 20 degrees of latitude. Changes on that scale could influence the global atmosphere and, in any case, are reflecting global scale atmospheric changes."

The study is focusing on these temperature anomalies, on the processes that cause them, and on the processes they trigger in the atmosphere; all in an area stretching from about long. 150°W eastward to the coast of South America, and about 15° latitude north and south of the Equator.

In parallel with the field experiment, NOAA scientists are conducting intensive studies of the existing mass of data already available on the equatorial Pacific and its overlying atmosphere. A third element in the study is a program of numerical modelling and analysis. The scientists will incorporate new data from the field experiment and other sources into existing ocean-atmosphere numerical models, with an eye to learning how the sea-surface temperature anomalies connect with atmospheric processes occurring on the time scales of climate.

Peterson Heads NMFS NE Regional Office

Allen E. Peterson, Jr., 39, has been selected as Director, Northeast Region, National Marine Fisheries Service, pending Civil Service approval, Terry L. Leitzell, National Oceanic and Atmospheric Administration's Assistant Administrator for Fisheries, has announced.

"Allen Peterson has had lengthy fisheries experience in the Massachusetts State Government, presently serves as its Director of Marine Fisheries, and is Chairman of the New England Fishery Management Council," said Leitzell. "His experience in legislative matters, liaison with industry, and a good background in marine fisheries will enhance our activities in New England."

Robert Hanks, Deputy Regional Director, will serve as Acting Director until Peterson joins the Department of Commerce agency.

In his new position, Peterson will succeed William Gordon who recently was appointed Director, Office of Resource Conservation and Management in the Service's headquarters in Washington, D.C.

Peterson, a native of Worcester, Mass., is a graduate of the University of Massachusetts, Amherst, where he received his B.S. degree in Wildlife Management in 1962, and his M.S. degree in Wildlife and Fisheries Biology in 1964. He joined the Massachusetts Department of Fisheries, Wildlife, and Recreational Vehicles in 1964 as an Assistant Fish and Game Biologist and has held progressively responsible positions in the Department.

He is married to the former Joan Fischer, Huntington, N.Y. They live in Sandwich, Mass., with their two children.

Grocery Chain Adopts Seafood DOC Inspection

A voluntary inspection program conducted by the National Marine

Fisheries Service aimed at assuring quality fresh seafood products has been adopted by the largest retailer owned supermarket cooperative in the United States.

Wakefern Food Corporation[1], Elizabeth, N.J., with 186 Shop-Rite stores in Connecticut, Massachusetts, New York, New Jersey, Delaware, and Pennsylvania, will be the first supermarket chain permitted to place a Department of Commerce Inspection mark on its full variety of fresh fish and shellfish. The round mark attests that the "Packed Under Federal Inspection" product has been found to be safe, wholesome, and of good quality at the time it was packed or received by Wakefern for distribution at its 93-acre distribution facility.

Those products that meet the DOC Grade A standards also will bear the mark. DOC seafood inspectors will monitor the product in the stores to assure quality maintenance.

Shop-Rite stores serve some 7½ million people each year. Annual sales of fresh seafood products by the Shop-Rite stores have grown from approximately 200,000 pounds a year in 1973 to over 3 million pounds representing from $5 to $6 million in retail sales in 1978.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

NOAA Creates New Oceanography Office

The National Ocean Survey (NOS) has established the Office of Oceanography to assist NOAA and the Department of Commerce to respond effectively to the many and diverse ocean and coastal initiatives over the next decade. Wesley V. Hull of Rockville, Md., was named Acting Director.

The new office assumes the responsibility for all the oceanographic and ocean dumping projects working in close coordination with the NOS Office of Marine Surveys and Maps. The Office collects and evaluates oceanographic and marine navigation data and performs analyses of physical phenomena pertaining to the sea and the Great Lakes, including tides, water levels, currents, the dynamics and physical properties of seawater, and shoreline and bottom configuration, as they affect waves and currents.

The Office also conducts comprehensive engineering surveys, estuarine investigations and studies of the Great Lakes and their outflow rivers, Lake Champlain, portions of the Hudson River, New York State Barge Canal, and Minnesota-Ontario border lakes. It directs the establishment and operation of the network of tide and water level stations, conducts tidal surveys for mapping seaward boundaries, and compiles and provides oceanographic data and tide and current predictions for use in marine navigation, civil engineering, and for solutions of environmental problems.

Hull, of the NOAA Corps, was formerly chief of the Oceanographic Division, NOS Marine Surveys and Maps. His assignments have included photogrammetry and hydrography, and he has served aboard the NOAA ships *Pioneer, Lester Jones, Oceanographer, Bowie,* and *Mt. Mitchell,* having commanded the latter two.

Hull received a B.S. degree in Civil Engineering from Oklahoma State University and a M.S. degree from Cornell. Immediately following graduation, he joined the Commissioned Corps of the U.S. Coast and Geodetic Survey, the predecessor of the NOAA Corps.

National Marine Mammal Laboratory Established

A research laboratory designed to serve as the center for national study of marine mammals has been established in Seattle, Wash., by the National Oceanic and Atmospheric Administration (NOAA).

The new facility was created in response to growing national and international concern for the welfare of marine mammals, and to permit research necessary for their conservation.

The National Marine Mammal Laboratory will take the lead in addressing marine mammal problems of national significance, as well as fulfilling America's commitments under international marine mammal agreements. NOAA scientists there will provide a pool of technical expertise to help in planning and carrying out research on local or regional marine mammal problems.

Establishment of the laboratory in Seattle recognizes the city's longstanding role as a center of Federal marine mammal research in the United States. With the passage of the Marine Mammal Protection Act of 1972, the Marine Mammal Division of NOAA's Northwest and Alaska Fisheries Center in Seattle assumed responsibility for most of the Department of Commerce's research programs on whales, seals, and sea lions.

The new laboratory will continue to be administered by the Northwest and Alaska Fisheries Center and will participate in the Center's Bering Sea Ecosystem Project, evaluating interactions among marine mammals, fish, and other major elements.

SABLEFISH TAGGING STUDIES PRODUCE RESULTS

In June and July, 1978, the Northwest and Alaska Fisheries Center of the National Marine Fisheries Service, NOAA, tagged sablefish, *Anoplopoma fimbria*, in the coastal waters of southeastern Alaska. These fish were tagged so scientists could study their distribution and migratory movements along the coasts of southeastern Alaska, British Columbia, Washington, Oregon, and California.

The study depends heavily on the cooperation of both domestic and foreign fishermen for the return of tags (Fig. 1) giving information on the sablefish and their capture. Nine tag returns in the first 9 months have provided some interesting preliminary results.

These returns come from three groups of sablefish, 707 fish in all, which were tagged and released at three different sites (Fig. 2). The first group, 217 fish, was released west of Cape Addington. One fish from this release was recovered by trap 28 days later south of Hippa Island, B.C., after a southerly migration of 136 miles. Another was caught west of Cape Scott, Vancouver Island, B.C., by a Japanese longliner after a movement of 332 miles in 71 days.

The second release of 174 fish occurred off Cape Ommaney. One fish was recovered locally after 27 days and another was captured south of Yakutat Bay, Alaska, by a Japanese longliner after a northwesterly migration of 216 miles in 100 days.

The remaining 316 fish were tagged near Cape Cross. There were five recoveries from this group. Three were recovered locally after 13, 15, and 40 days of freedom and distances traveled of about 4, 7, and 40 miles, respectively. These fish were captured by a U.S. longline vessel, the *Urania*. Two additional tagged fish were taken by the aforementioned Japanese longliner fishing the Yakutat Bay area after being free 75 and 85 days during which they migrated 174 and 110 miles, respectively.

While results based on so few recoveries cannot be conclusive, they do indicate that some sablefish in the study area travel considerable distances but others move very little. These results suggest that there may be a positive relationship between the length of time a tagged sablefish is free

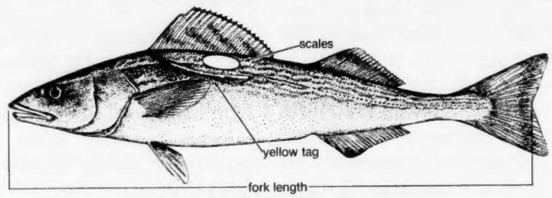

Illustration courtesy of Fisheries and Marine Service, Environment Canada

Figure 1.—Tagged sablefish are sought by scientists with the NMFS Northwest and Alaska Fisheries Center, 2725 Montlake Blvd. East, Seattle, WA 98112. Position of the tag is shown, along with scale sampling area and fork length measurement.

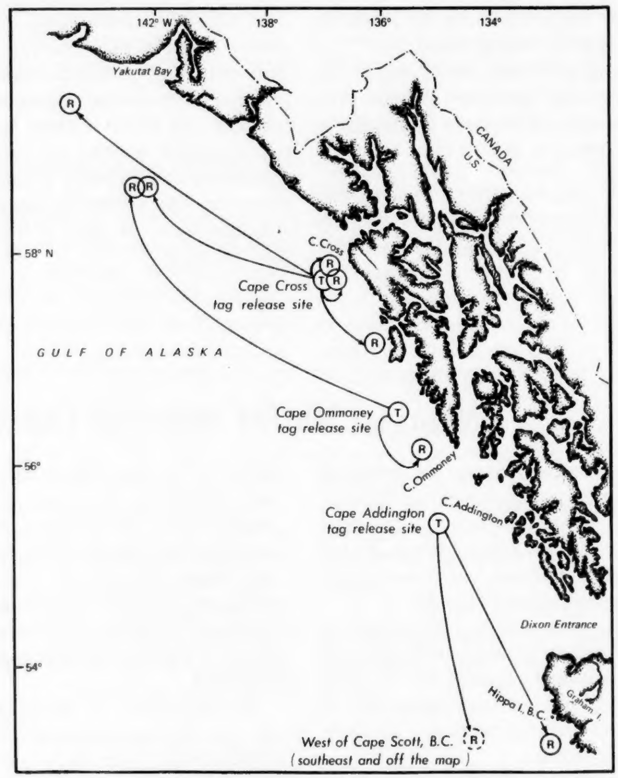

Figure 2.—Sites where tagged sablefish were released and subsequently recovered during 1978. The lines show the direction, but not necessarily the path of migration of the captured and tagged sablefish. A circled "T" represents tagging sites and a circled "R" indicates the recovery sites.

and the distance traveled. While this may be the case, the results of previous sablefish tagging studies have failed to demonstrate such a relationship. More tag returns are expected from the 1978 releases and these, combined with a continuation of the tagging program this year, should provide considerably more insight on the migrational behavior of sablefish in Alaska waters.

Sea Grant Launches International Effort

The National Oceanic and Atmospheric Administration (NOAA) has announced a program of international cooperation in marine research with a number of developing nations to aid their efforts and to promote exchange of information on oceanic and coastal resources. Under the program, funded by $913,400 in grants from NOAA, seven U.S. academic institutions associated with the agency's Sea Grant College Program will undertake cooperative marine programs with counterparts in Chile, Costa Rica, Malaysia, Mexico, Israel, and Colombia.

Primary emphasis will be on education and training, Ned A. Ostenso, Director of the Commerce Department's National Sea Grant College Program, said. Research and advisory service functions will also be included. The program was authorized by legislation in 1976, and is coordinated with the U.S. Department of State.

The University of Deleware Sea Grant College Program received a 2-year, $303,500 grant for a cooperative marine studies program with the University of Costa Rica; while a $199,900, 2-year grant was awarded the University of Miami to support a marine resources and environmental sciences training program in cooperation with several educational institutions in Colombia, and coordinated with the Colombian Oceanographic Commission.

The Sea Grant Program at the Virginia Institute of Marine Science (VIMS) is using a $131,400 grant to train personnel in Israel in wave measurement and modeling techniques and to improve Israeli marine advisory services in wave information and coastal zone planning. The VIMS project is for a 2-year period.

The University of Rhode Island Sea Grant College Program has received $95,000 for a 1-year project in Malaysia with the University of Malaya and the University Pertinian Malaysia. This project will develop academic programs in fisheries management, coastal zone management, and related fields, plan future research projects, and outline a structure for a local marine extension service.

The Oregon State University Sea Grant College Program is assisting Latin American nations in the development of appropriate levels of competence in marine resource conservation with its $90,000, 1-year grant. Chief participating institution in Latin America is Catholic University of Valparaiso in Chile.

An award of $72,000 to the New York Sea Grant Institute is strengthening marine science capabilities in Chile. The 2-year project, carried out with the University of Concepcion, concentrates primarily on training faculty members of the Department of Marine Biology and Oceanography in coastal zone management techniques.

The Louisiana State University Sea Grant College Program has been granted $21,600 for a 1-year project in Mexico. Among the tasks there are identification and quantification of the ecological associations between Terminos Lagoon at Campeche and the fisheries.

New CZ Advisory Group Members Are Selected

Seven new members have been appointed by Commerce Secretary Juanita M. Kreps to serve on the National Coastal Zone Management Advisory Committee.

The new appointees are Joseph Bodovitz, a consultant from Mill Valley, Calif., and formerly executive director of the California Coastal Commission; Ogden Doremus, an environmental attorney from Meter, Ga.; Patrick W. Kelly, head of the American Petroleum Institute's Coastal Zone Management Task Force, from Dallas; Steven A. McMillan, vice president of Earle, McMillan, and Niemayer, from Bay Minette, Ala.; Michele Perault, coastal coordinator for the Sierra Club, from Berkeley, Calif.; Shirley H. Taylor, chairwoman of the Sierra Club Task Force on Coastal Zone Management, from Tallahassee, Fla.; and Henry Wheatley, president of Ocean Environments, Inc., from St. Thomas, Virgin Islands.

They will join the four other members of the Advisory Committee, which was established by the Coastal Zone Management Act of 1972 to the policy recommendations to the Secretary of Commerce on such matters as proposed legislation, Federal regulations, and the administration of the coastal zone management program.

Caribbean Monk Seal Declared Endangered

The Caribbean monk seal, indiscriminately killed for hides and oil since early Spanish exploration of the western hemisphere, has been listed as an endangered species by the National Oceanic and Atmospheric Administration's National Marine Fisheries Service.

Scientists with the Commerce Department agency fear the animal may already be extinct since surveys and studies have failed to locate any of the mammals in its former habitat in the Gulf of Mexico and Caribbean Sea.

Under the Endangered Species Act of 1973, an endangered species is one that is in danger of becoming extinct throughout all or a significant part of its range and is protected from any contact by man.

Karl W. Kenyon, a noted marine mammalogist, conducted an extensive aerial survey of the Caribbean monk seal's former habitat in the Gulf of Mexico and Caribbean Sea in 1973 and failed to locate any of the seals. This survey and a study by NMFS scientist Dale W. Rice provided the basis for the assumption that the species is extinct.

Canadian Fishing Industry Has "Excellent Year" in 1978

Canada's Fisheries and Oceans Minister Roméo LeBlanc termed 1978 a bonanza year for the Canadian fishing industry as he released preliminary fisheries statistics which show that for the third year in a row Canadian fishermen and processors have set a new record in terms of earnings.

"Our projected figures for 1978 show that while landings are up 8 percent, landed values are up 35 percent, a figure that has more than doubled in 3 years. This was possible because we got a better dollar for most species," said LeBlanc.

Total landings in Canada (including inland fisheries) have been projected at 1,358,000 metric tons (t) valued at 652,790,000 compared with 1,254,930 t valued at $485,263,000 in 1977. The total marketed value of products in 1978 is expected to exceed $1.4 billion compared with $1.2 billion in 1977.

Atlantic coast products were projected to reach a market value of close to $1 billion compared with $767 million in 1977, while on the Pacific coast, the market value was expected to reach $450 million compared with the 1977 figure of $365 million.

"It appears 1978 has been a bonanza year for Canadian fishermen," said LeBlanc. "Their incomes have, in most cases, risen significantly. Employment in fish plants is the steadiest ever and most fishing communities are looking brighter, with more money. I look forward to this trend continuing into 1979 and well into the 1980's."

The projected value of exports for 1978 should be close to $1.1 billion compared with $816 million in 1977. Exports to the United States indicated an increase of 5 percent in volume and 28 percent in value over the last year, while exports to the European Economic Community countries showed a strong growth from last year of 17 and 39 percent in volume and value, respectively, the Minister noted. The projected value of imports also increased from $221 million in 1977 to $253 million in 1978. Per capita consumption in 1978 was also expected to reach 7.9 kg compared with 7.6 kg in 1977. "It appears that more and more Canadians have turned to fish in the last year," said LeBlanc.

Canadian marine[1] fish landings and landed values, January-December 1978.

Species	Landings (t) 1977	[2]1978	% Change	Landed values (1,000) 1977	[2]1978	% Change
Atlantic total[3]	1,003,074	1,119,800	+ 12	288,252	393,780	+ 37
Groundfish	515,355	603,300	+ 17	120,968	159,340	+ 32
Cod	237,622	290,000	+ 22	61,743	82,600	+ 34
Redfish	66,594	74,000	+ 11	9,781	12,400	+ 27
Flounders & soles	133,989	143,400	+ 7	27,876	31,600	+ 13
Pelagic & est. fish	287,028	309,300	+ 8	41,357	62,020	+ 50
Herring	228,993	235,000	+ 3	24,044	38,000	+ 58
Shellfish	200,691	207,200	+ 3	120,211	164,020	+ 36
Scallop	116,849	110,000	- 6	44,092	63,800	+ 45
Lobster	17,833	19,000	+ 7	56,614	69,700	+ 23
Squid	38,544	40,000	+ 4	5,128	7,800	+ 52
Pacific Total	204,821	191,440	- 7	167,905	228,910	+ 36
Groundfish	29,866	32,850	+ 10	18,322	26,000	+ 42
Pelagic & est. fish	166,233	150,090	- 10	143,307	195,210	+ 36
Herring	97,172	81,000	- 17	32,461	55,000	+ 69
Salmon	65,582	+ 1	108,725	138,000	+ 27	
Shellfish	8,722	8,500	- 3	6,276	7,700	+ 23
Shrimp	2,801	1,500	- 46	1,714	1,600	- 7

[1]Table does not include inland fisheries landings which were estimated at 46,760 t and valued at $30,100,000.
[2]Based on preliminary projected figures. Source: Intelligence Services Division, Marketing Services Branch, Fisheries and Oceans, Canada.
[3]Values for Atlantic Total include miscellaneous items.

Atlantic Coast

Total landings on Canada's Atlantic coast amounted to 1,119,800 t valued at $393,780,000 compared with 1,003,074 t valued at $288,252,000 in 1977. "One significant reason for the jump in Atlantic coast landings was the huge rise in the Canadian cod catch. Atlantic cod landings totalled 290,000 t valued at $82,600,000, showing increases of 22 and 34 percent in volume and value, respectively, over last year," said LeBlanc.

Other species which showed remarkable rises in value over the previous year include herring, whose landed value increased 58 percent, and squid with an increase in landed value of 52 percent.

Pacific Coast

Pacific coast landings totalled 191,440 t valued at $228,910,000 compared with 204,821 t in 1977 valued at $167,905,000. "What is significant on the west coast is that while Pacific herring landings decreased by 7 percent from the previous year, the landed value increased by 69 percent. As well, salmon landings totalled 66,500 t, about the same as in 1977, but the market value is expected to reach a record high of $138 million, an increase of 27 percent over 1977," said Le Blanc.

Canada Contracts for New Research Trawlers

Canada's Fisheries and Oceans Minister Roméo LeBlanc announced in March that work would begin immediately on construction of two $10 million fisheries research stern trawlers to be used in support of Canada's fish-

eries management programs in that nation's 200-mile zone off the east coast.

The contract to build the two 49.5-m (165-foot) vessels was awarded by the Department of Supply and Services to Ferguson Industries Ltd.[1], of Pictou, Nova Scotia. Construction time is estimated at approximately 2 years. According to LeBlanc, the contract is expected to provide employment for an average of 150 shipyard workers over the length of the contract.

One of the new research trawlers will be a replacement for the 20-year-old *A. T. Cameron*, which conducts fisheries research out of St. John's, New Foundland. The other new research trawler will be based at Halifax, N.S.

The two new vessels will be used for research work extending from George's Bank to northern waters off Labrador, involving biological sampling, resource surveys, and stock assessments essential for the efficient management of fisheries in Canada's 200-mile zone. This will be in addition to the research work now being carried out under charter arrangements by the large ice-strengthened trawlers *Gadus Atlantica* and *Lady Hammond.*

Of steel construction, the new trawlers will be powered by a single diesel engine driving a controllable-pitch propeller to provide an operating speed of about 12.5 knots. The vessels will be fitted with the latest commercial-type fishing equipment and fully-equipped scientific laboratories to enable studies to be undertaken while at sea.

Canadian Fish Technology Program Cuts Reviewed

Canadian Fisheries Minister Roméo LeBlanc reports that he has completed his review of cutbacks in fisheries technology development programs, announced previously under the federal government's proposals to reduce spending.

The Minister made it clear that there was no intention to reduce essential fisheries research. In fact, since the 200-mile limit came into effect on 1 January 1977, the department has hired 125 additional researchers and research spending during the current year has gone up by $14 million. It is intended to further increase this research effort in 1979.

As regards to the technological programs, high priority will continue to be given to exploratory fishing and gear and vessel design and demonstrations, the Minister said. Neither will there be any reduction in effort on projects related to harvesting and processing of underutilized species and studies on preservation of fish quality and fish spoilage.

LeBlanc said the fisheries technological laboratories at Halifax and Vancouver would not be closed down. However there will be selected reductions in program and significant reductions in the level of technical and administrative support at these establishments.

Among the technological projects affected under the cutbacks and program reductions are those related to packaging and storage of fishery products, work on the utilization of marine oils, some studies on paralytic shellfish poisoning and reproductive biochemistry, and some associated technical support services.

LeBlanc said the projects being cut were those which largely benefit the secondary industry. It was felt that this development work should be the responsibility of the private sector.

"With the resurgence of the fishing industry in the past year or so, companies should now be in a position to meet these development costs themselves," the Minister added.

In those activities where a relationship exists with other programs being undertaken by the department, economies will be achieved by combining and restructuring operations wherever possible.

Every effort will be made to find alternative employment for those employees affected by the cuts, LeBlanc said. In order to facilitate this, affected personnel were to be maintained on strength until 31 May 1979.

PRC Shows Interest in Norwegian Fish Vessels

According to the head of marketing in the Norwegian company, Norcontrol, Egil Strupe, the People's Republic of China is showing considerable interest in the acquisition of Norwegian fishing vessels. It was expected that an official inquiry from the Chinese authorities would soon be forthcoming in respect of five such vessels, of between 150 and 300 t.

In addition to these, Strupe also reports that the Chinese are thought to be interested in buying up existing fishing tonnage from Norway, primarily vessels of between 3 and 4 years old. This interest is also thought to extend to fish-processing equipment, and there are indications that Norwegian expertise and assistance may well be called upon in connection with the development of Chinese fish off-loading depots.

This information was brought back to Norway by Strupe following a 3-week visit to Peking late last year, where Norcontrol's Chinese agents requested him to establish contact with Norwegian yards and fishing companies with a view to assisting the present build-up of a modern Chinese fishing industry. The initial purpose of Strupe's Chinese visit was to negotiate the sale of his company's navigation and engine-room simulators to the People's Republic of China. These are to be installed at the fishing and shipping center of Talien. The simulators are primarily designed for the training of officers in the rapidly expanding Chinese merchant fleet. The programs may, however, be developed further in order to cater to the training needs of fishing-vessel crews with reference to actual work and navigational situations, according to the Norwegian Information Service.

The contract to the Horten-based

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Norwegian company is estimated to be worth some $8 million NOK, with a training package in addition worth another million. Delivery is scheduled to take 14 months from placing the order, and a group of Chinese maritime personnel travelled to Horten early this year to undergo several months' introductory training. (Source: Norinform).

Soviet Aquaculture Will Stress Inland Fisheries

The Communist Party Central Committee and the Council of Ministers of the Soviet Union have adopted a resolution ("On Measures to Further Develop Fish Breeding and to Improve the Fish Catch in the Freshwater Ponds of the Country") outlining the basic direction of Soviet inland fishing to 1985. In this period the freshwater catch target is to be twice the 1977 level with the total catch increasing to 924,000 t.

In the 1981-85 period the yield per hectare is slated to increase by 1.8 times in ponds and twofold in commercial lakes. During the 1981-85 period capital investment for construction of fish breeding projects will be about twice that for the years 1976-80, creating 150,000 hectares of new ponds and 600,000 hectares of lakes for commercial use. Presently, state fisheries and collective fish farms alone control 25 million hectares of lakes, 6 million hectares of reservoirs, 200,000 hectares of breeding ponds, and 315,000 km of rivers. The Ministry of Land Reclamation and Water Management, the Ministry of Food Industries, and other ministries have 11 million hectares of freshwater bodies under their jurisdiction.

In order to reach the 1981-85 targets, the Soviet fishing industry must change over from extensive to intensive inputs, emphasizing increased labor productivity and quality control. The production of stocking equipment will also be stepped up. The new resolution obliges a number of agencies and ministries to aid in automation and mechanization of commercial fishing operations as well as to provide better granulated mixed foods for fish.

A series of canals, nurseries, and reservoirs will be built and 1.8 million hectares of land will be drained for agricultural and aquacultural purposes in an area where 25 percent of the Soviet population is located. Such proximity to consumers will eliminate the need for many freezing, storage, and processing installations.

Though ocean fishing will be developed in a parallel manner, inland fishing is being emphasized in order to lessen the influence of foreign policy factors which may affect ocean fishing. (Source: LSD 79-3.)

Unless otherwise noted, material in this section is from the Foreign Fishery Information Releases (FFIR) compiled by Sunee C. Sonu, Foreign Reporting Branch, Fishery Development Division, Southwest Region, National Marine Fisheries Service, NOAA, Terminal Island, CA 90731, or the International Fishery Releases (IFR) or Language Services Daily (LSD) reports produced by the Office of International Fisheries, National Marine Fisheries Service, NOAA, Washington, DC 20235.

Norwegian Longlining to Be Made More Effective

The Norwegian Fishery Technology Research Institute at Bergen has undertaken a study of the reactions of cod and other species to bait and hooked lines, with a view to improving the catches attributable to longline fishing activities. The researchers have made use of submersible TV cameras, which have shown that the fish are able to escape from the hooks with far too great ease, after adding insult to injury by making off with the bait.

As part of the tests which have been carried out, a new hook design has been introduced which has reportedly proved to be far more effective in retaining the fish after the initial bite. Use of the hook has already proved its value in the form of increased catch effectiveness in connection with longlining. However, the newly designed longline has yet to be put into production, following the necessity for carrying out further parts of the overall research program. The problem is that longlining is employed in vastly differing geographic areas, at depths of down to 1,000 m.

The studies which have been made to date have been centered on activities off the coast of Finnmark during the summer and autumn. It was felt that the conditions in that area cannot be considered representative for all the areas where this fishing technique is employed. Different times of the year may also provide varying results. One of the attendant problems with the research program is the need for improved lighting conditions at great depths for monitoring purposes. The Ocean Research Institute is cooperating in the program in order to help overcome these difficulties. (Source: Norinform.)

Kamentsev Is Soviet Fisheries Minister

According to Soviet press reports, the Presidium of the Supreme Soviet of the U.S.S.R. has relieved Aleksandr Akimovich Ishkov from the duties of Minister of Fisheries owing to his retirement. Vladimir Mikhaelovich Kamentsev has been named to replace Ishkov as Minister of Fisheries. (Source: LSD 79-3.)

Japan's Purchases of Alaska King Crab Soar

Early reports pegged king crab shipments from Alaska to Japan at about 12,000 t last year, approximately triple the amount purchased by Japan in 1977. Late wholesale prices of the imported Alaska king crab being charged by importers in the Tokyo area were reportedly ¥1,750-1,850/kg (US$4.06-4.17/pound at ¥196=US$1) for boiled products, down from 1977. Production of king crab in Alaska during the past season was reported to be about 40,000-50,000 t. (Source: FFIR 78-15.)

Editorial Guidelines for *Marine Fisheries Review*

Marine Fisheries Review publishes review articles, original research reports, significant progress reports, technical notes, and news articles on fisheries science, engineering, and economics, commercial and recreational fisheries, marine mammal studies, aquaculture, and U.S. and foreign fisheries developments. Emphasis, however, is on in-depth review articles and practical or applied aspects of marine fisheries rather than pure research.

Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

The Manuscript

Submission of a manuscript to *Marine Fisheries Review* implies that the manuscript is the author's own work, has not been submitted for publication elsewhere, and is ready for publication as submitted. Commerce Department personnel should submit papers under completed NOAA Form 25-700.

Manuscripts must be typed (double-spaced) on high-quality white bond paper and submitted with two duplicate (but not carbon) copies. The complete manuscript normally includes a title page, a short abstract (if needed), text, literature citations, tables, figure legends, footnotes, and the figures. The title page should carry the title and the name, department, institution or other affiliation, and complete address (plus current address if different) of the author(s). Manuscript pages should be numbered and have 1½-inch margins on all sides. Running heads are not used. An "Acknowledgments" section, if needed, may be placed at the end of the text. Use of appendices is discouraged.

Abstract and Headings

Keep titles, heading, subheadings, and the abstract short and clear. Abstracts should be short (one-half page or less) and double-spaced. Paper titles should be no longer than 60 characters; a four- to five-word (40 to 45 characters) title is ideal. Use heads sparingly, if at all. Heads should contain only 2-5 words; do not stack heads of different sizes.

Style

In style, *Marine Fisheries Review* follows the "U.S. Government Printing Office Style Manual." Fish names follow the American Fisheries Society's Special Publication No. 6, "A List of Common and Scientific Names of Fishes from the United States and Canada," third edition, 1970. The "Merriam-Webster Third New International Dictionary" is used as the authority for correct spelling and word division. Only journal titles and scientific names (genera and species) should be italicized (underscored). Dates should be written as 3 November 1976. In text, literature is cited as Lynn and Reid (1968) or as (Lynn and Reid, 1968). Common abbreviations and symbols such as mm, m, g, ml, mg, and °C (without periods) may be used with numerals. Measurements are preferred in metric units; other equivalent units (i.e., fathoms, °F) may also be listed in parentheses.

Tables and Footnotes

Tables and footnotes should be typed separately and double-spaced. Tables should be numbered and referenced in text. Table headings and format should be consistent; do not use vertical rules.

Literature Citations

Title the list of references "Literature Cited" and include only published works or those actually in press. Citations must contain the complete title of the work, inclusive pagination, full journal title, the year and month and volume and issue numbers of the publication. Unpublished reports or manuscripts and personal communications must be footnoted. Include the title, author, pagination of the manuscript or report, and the address where it is on file. For personal communications, list the name, affiliation, and address of the communicator.

Citations should be double-spaced and listed alphabetically by the senior author's surname and initials. Co-authors should be listed by initials and surname. Where two or more citations have the same author(s), list them chronologically; where both author and year match on two or more, use lowercase alphabet to distinguish them (1969a, 1969b, 1969c, etc.).

Authors must double-check all literature cited; they alone are responsible for its accuracy.

Figures

All figures should be clearly identified with the author's name and figure number, if used. Figure legends should be brief and a copy may be taped to the back of the figure. Figures may or may not be numbered. Do not write on the back of photographs. Photographs should be black and white, 8- × 10- inches, sharply focused glossies of strong contrast. Potential cover photos are welcome but their return cannot be guaranteed. Magnification listed for photomicrographs must match the figure submitted (a scale bar may be preferred).

Line art should be drawn with black India ink on white paper. Design, symbols, and lettering should be neat, legible, and simple. Avoid freehand lettering and heavy lettering and shading that could fill in when the figure is reduced. Consider column and page sizes when designing figures.

Finally

First-rate, professional papers are neat, accurate, and complete. Authors should proofread the manuscript for typographical errors and double-check its contents and appearance before submission. Mail the manuscript flat, first-class mail, to: Editor, *Marine Fisheries Review*, Scientific Publications Office, National Marine Fisheries Service, NOAA, 1107 N.E. 45th Street, Room 450, Seattle, WA 98105.

The senior author will receive 50 reprints (no cover) of his paper free of charge and 100 free copies are supplied to his organization. Cost estimates for additional reprints can be supplied upon request.

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